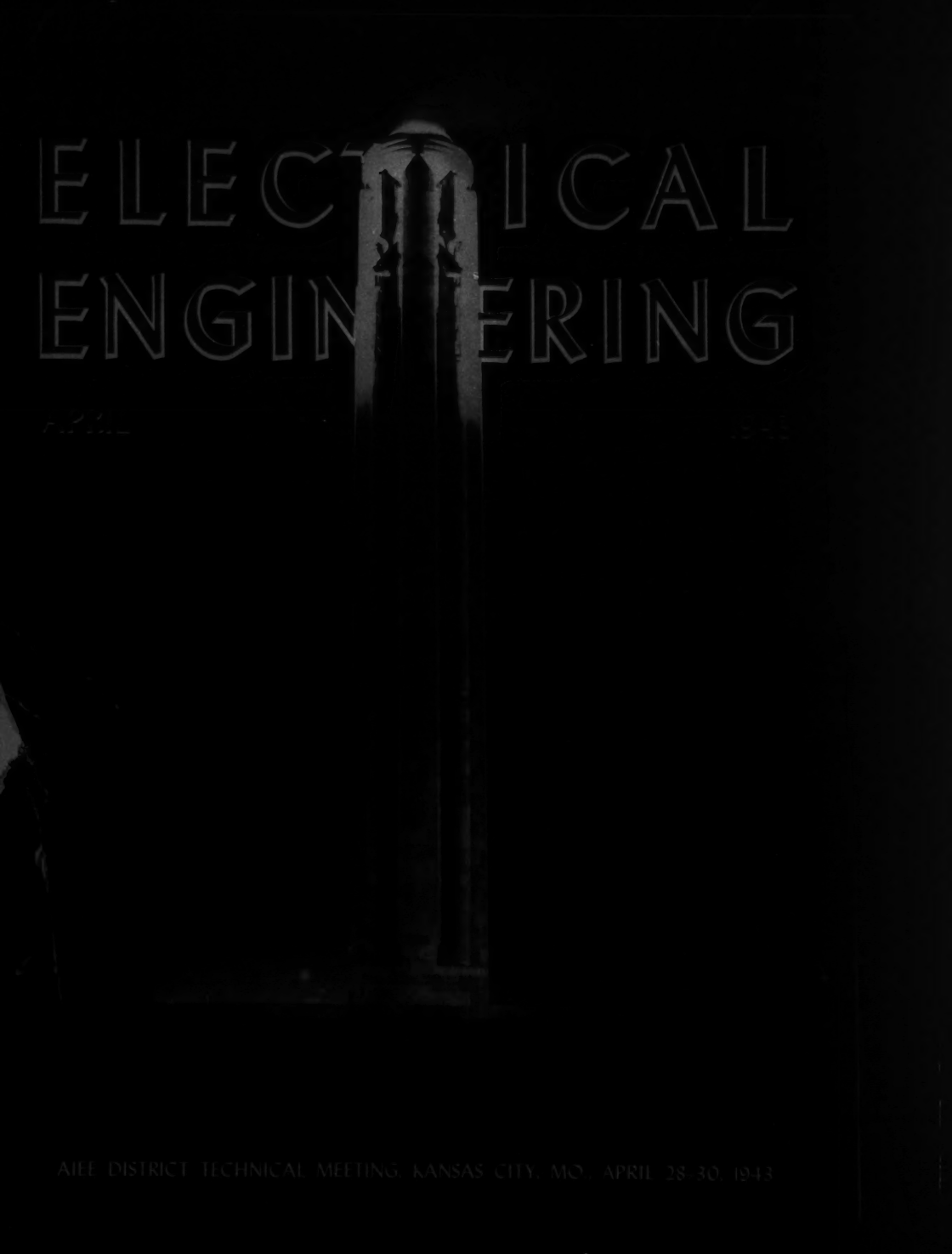
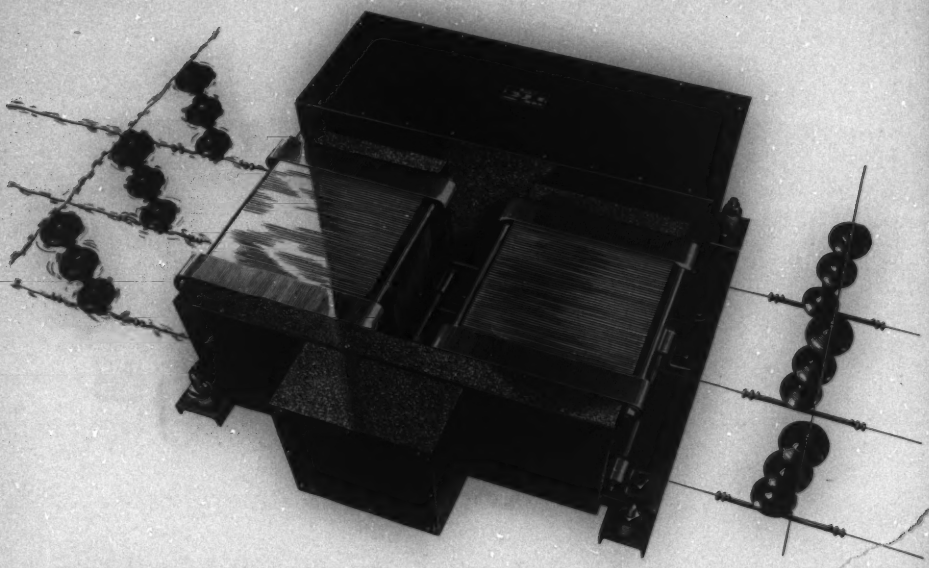
ELECTRICAL ENGINEERING



AIEE DISTRICT TECHNICAL MEETING, KANSAS CITY, MO., APRIL 28-30, 1943

Industry steadies its "nerves"



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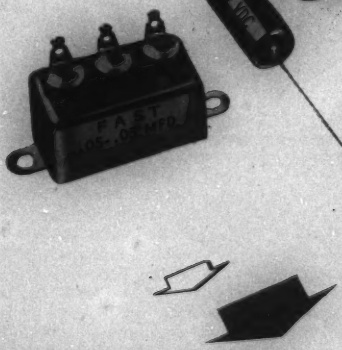

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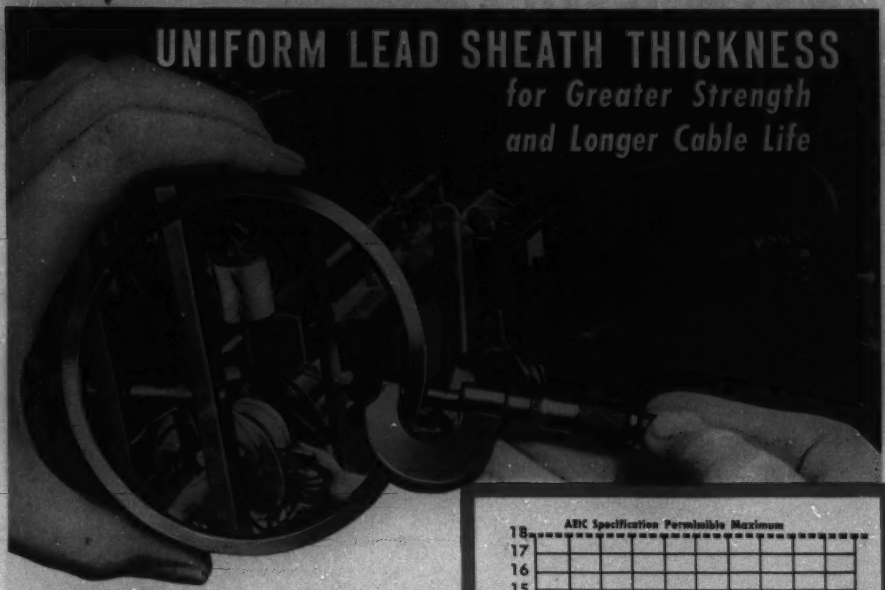

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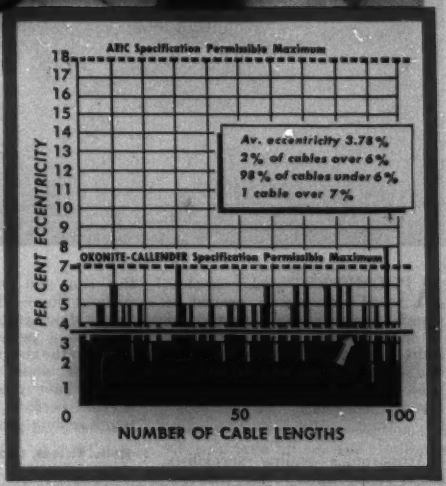

● Individual lead sheath eccentricity record. Results of actual micrometer measurements made on 100 consecutive lengths of Okonite-Callender Paper-Insulated Lead-Covered Cable, manufactured in regular factory production during January, 1943, and tested for sheath eccentricity in accordance with procedure required by A.E.I.C. specifications.

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It can be used instead of rotating machinery for converting A-C to D-C

Industry uses the G-E sealed ignitron — a steel-jacketed electronic tube — in many ways. One of the most important is as a power rectifier — converting alternating current to direct current.

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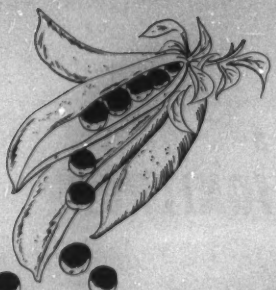

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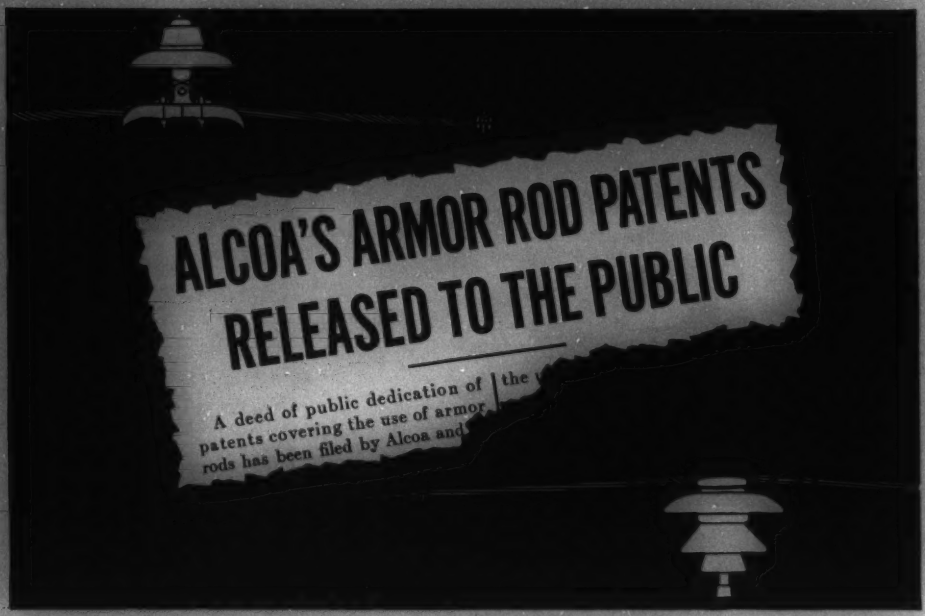
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APRIL

1943

The Cover: The Liberty War Memorial, Kansas City, Mo., where the AIEE South West District technical meeting will be held (*see pages 168-70*), commemorates World War I as the nation engages in the struggle of World War II.

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G. Ross Henninger
Editor (on leave)

Floyd A. Lewis
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Group of 1943 Science Talent Search Winners leaving the Pan-American Union Building after discussing South American relations with Dr. L. S. Rowe, Director-General.

Prospecting for future scientists

Every step forward in science brings with it a need for more scientists. Not technicians merely, but men and women who are capable of creative achievement.

Where are they to be found?

It seems highly probable that aptitude for creative achievement in science can be discovered as early as the senior year in high school.

It is quite certain that early discovery of ability helps crystallize the interests of the students and stimulates them to further activity.

For these reasons, Science Service, Science Clubs of America and Westinghouse are cooperating in an annual Science Talent Search. Methods employed in the Science Talent Search, including the science aptitude tests, were devised by Dr. Harold A. Edgerton, Ohio State University, and Dr. Steuart Henderson Britt, Office of Psychological Personnel, National Research Council.

Each year, 40 boys and girls selected on the basis of the criteria set up by Dr. Edgerton and Dr. Britt, are taken to Washington as guests of Westinghouse. There, after further examinations and interviews, those who qualify receive Westinghouse Science Scholarships ranging from $100 to $2400.

Last year, 20 Westinghouse Science Scholarships were awarded, but every boy and girl selected for the trip received offers of scholarship help from leading colleges and universities.

Every one entered college.

Every one is making a scholastic record considerably above the average.

Since the Science Talent Search is only in its second year, there are yet no data on the correlation between aptitude as measured by the methods employed and actual achievement in science. Dr. Edgerton and Dr. Britt have, however, begun a projected ten-year study of these boys and girls, covering their work in college and the early part of their after-college careers.

Full information on the Science Talent Search, including reprint of an article by Dr. Edgerton and Dr. Britt describing the methods employed, will be sent on request. Write to Science Service, 1719 N Street, Washington, D. C., or to School Service, Westinghouse Electric & Manufacturing Co., 306 Fourth Ave., Pittsburgh, Pa.

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The Role of Lighting in Accident Prevention

H. L. LOGAN
MEMBER AIEE

ACCORDING to Rear Admiral W. H. P. Blandy, speaking to the National Safety Congress in Chicago, Ill., on October 27, 1942, "Since Pearl Harbor, almost as many people have been accidentally killed in the United States, including 42,600 war workers, as have been killed by German bombing in England *in three years!*

"Since Pearl Harbor, *more* Americans have been *permanently* disabled by accidents on the home front than the total of military forces wounded, captured, and killed in action.

"Since Pearl Harbor, accidents have cost us more than 3,000,000,000 man-hours."

At this time when all available man power is needed for war production, it is important that the causes of industrial accidents be investigated and eliminated. Inadequate lighting is one of these causes, although its relation to accident rate has not always been clearly perceived. Statistics indicate that industrial accident rate decreases with an increase in illumination levels, but that the decrease lessens as lighting levels are raised.

To this toll must be added an economic loss of at least $3,750,000,000, according to the National Safety Council. The accident toll is so huge that it is a major handicap to winning the war.

ACCIDENTS ARE PREVENTABLE

Once upon a time accidents were accepted as an inescapable feature of industry. We now know that accidents can be prevented, and as our supply of workers is limited we cannot afford to lose them through accidents. Wars may not be won by armies that follow the slogan, "safety first," but they may be lost by managements and workers that do not.

Much is known now about the technique of accident prevention. A profession has grown up that makes this subject its exclusive field—the profession of "safety engineering." Its members have many years of successful practice behind them, but right now they are faced with a new combination of circumstances. We have become a 24-hour nation—the greater part of our expanded production occurs under artificial lighting; the production rate has tripled or quadrupled; plant areas and facilities are occupied by two, three, and four times the number of workers for which they were planned; many workers are new and inexperienced, others are old, some are females, most work longer hours—so that the trend of the accident curve has been reversed, and it is rising.

LIGHTING AND ACCIDENTS

Now that every preventive measure is "worth its weight in tanks and guns," national attention has been focused on the accident menace, and many means are being sought to hold it in check. If these various means assured complete success, there would be no need to add to the library that is already available on the subject of accident prevention. The justification for these remarks lies in the fact that *all* of the causes of the accident rate are not under satisfactory control and specifically, that one of these causes—the close dependence of accidents on sight, and so on light—is not understood sufficiently. There will be little new in the evidence presented here, but this evidence shows relationships in its collected form that were not easy to see as long as it remained scattered.

There is, of course, a general vague belief that lighting is somehow tied up with a certain percentage of accidents, but a pious belief in a connection between light and safety is of little practical help. Much wider and clearer knowledge of the use of good lighting in protecting workers is needed to stimulate its use as a safeguard.

The black-out has brought home to large numbers of people their almost complete dependence on visibility for safety. They have discovered that they can hardly move ten paces in a complete black-out without running the risk of at least a minor accident. The English people cite the black-out as the most dismaying feature of the war. In areas where it is most severe, pedestrian fatalities have risen 400 per cent over prewar figures, despite a drastic reduction in traffic.[1]

The personal experience of everyone supports the statement that an accident is probable in the sudden absence of sight or light. Light, therefore, replaces the *probability* of accidents with mere possibilities, and reflection makes clear that these possibilities may be further reduced by the kind of lighting that provides certainty of seeing.

VISIBILITY AND TRAFFIC ACCIDENTS

The clearest specific connection between uncertain seeing caused by poor visibility and accidents has been shown in traffic accident studies. L. J. Schrenk[2] reports that automobile traffic fatalities at night in the city of Detroit, Mich., became seven times the daytime fatalities from 1934 to 1936, when street lighting was reduced

H. L. Logan is managing engineer in the Controlens division of the Holophane Company, Inc., New York, N. Y.

owing to the depression. These fatalities dropped to 1.4 times the daytime rate in 1937, when the street lighting was restored.

A study of traffic accidents[3] in 46 cities the first year, 227 cities the second year, and 60 cities the third year of a 3-year investigation showed that fatalities owing to a lighting cause were from 46 to 50 per cent of the total nighttime fatalities. Nonfatal accidents showed the same proportions.[3]

G. D. Newton,[3] Travelers Insurance Company, Hartford, Conn., made an investigation[3] on a national scale of the number of fatalities occurring during the four evening rush hours, 5 p.m. to 9 p.m., and those occurring during the morning rush hours, 6 a.m. to 10 a.m. The evening fatalities were 281 per cent of the morning fatalities.

A comparison of police records,[4] 5 a.m. to 7 a.m., winter and summer (dark in winter, light in summer), and always a period of relatively light traffic, shows winter fatalities 218 per cent of summer fatalities.[5]

It appears that decreased visibility on the highways increases the number of fatalities that would occur otherwise from two to seven times. It is significant to note that recent dim-out and black-out experience here and abroad abundantly reinforces these figures.

This "law," that the provision of proper visibility automatically reduces night traffic accidents from 50 to 88 per cent, is of great importance to industrialists when coupled with the fragmentary, but confirming, data from industrial tests.

So close and constant is the relationship between visibility and traffic accidents that when during the depression many municipalities economized on their street lighting, night accidents climbed *in all cases*. Conversely, when former lighting levels were restored, the accident rates dropped. Traffic experts now have proved that the rate of night accidents can be dropped to the rate of day accidents by the adequate use of artificial lighting.[5]

VISIBILITY AND INDUSTRIAL ACCIDENTS

Insurance experts[4] after long experience with industrial accidents, charge 15 per cent to poor illumination. Doctor Frank Allport, of the American Society of Safety Engineers, stated some years ago that improper illumination is the basic cause of 25 per cent of industrial accidents. Doctor J. R. Wittekind, chairman of the industrial relations committee of the American Optometric Association, says that poor vision (defective eyes and poor lighting) are responsible for 20 per cent of the accidents.

These are just the opinions of experts, based on their own particular experiences, and can be said to cover the group of accidents indisputably caused by poor lighting. They would disappear automatically upon the adoption of proper seeing conditions.

Between this 15 to 25 per cent group and accidents in which vision plays no part, is an indeterminate group in which light and vision enter in various degrees to cause accidents. Better seeing conditions would not eliminate, but would reduce this group.

One of the obstacles the investigator meets in his efforts to arrive at definite figures in this matter is caused by the unfamiliarity of safety people with visibility phenomena, and their inability to recognize light as a cause in individual cases. Sight and light lie unsuspected under mountains of reports.

There is space in this article to treat only the broad aspects of the light-accident problem, and so individual cases illustrating the way in which poor visibility causes accidents must, of necessity, be omitted. A study of the papers in the bibliography is suggested in this connection.

Lighting literature includes various instances where the accident rate dropped in a department, or even in an entire plant, when the lighting conditions were improved. In one case the average illumination in the punch press department of a company was raised from 2 foot-candles to 19 foot-candles at work level. The frequency of accidents dropped 54 per cent.[6] This is in line with the rate of drop observed in traffic accidents when visibility is improved.

In another plant a rise to 30 foot-candles from 8 foot-candles caused a drop of 11 per cent in the accident rate. This is reasonable, as this plant had enough general light to provide fair seeing conditions at the original level, and did not, therefore, have so severe an accident rate as the case mentioned previously. By adopting 8 foot-candles originally this plant had saved itself from many of the accidents. The rise to 30 foot-candles simply eliminated the remainder of the "light-vision" accidents that could still occur at the 8 foot-candle level.

R. E. Simpson of the Travelers Insurance Company cites the most striking case. A factory employing 1,000 workers had an annual accident rate of 425. A new lighting system was followed by a drop to 170. In this report the lighting levels were unfortunately not given. An interesting feature of this report is that compensation payments dropped from $59,500 to $23,800 annually, which was a saving of nine times the cost of the improved lighting.[6]

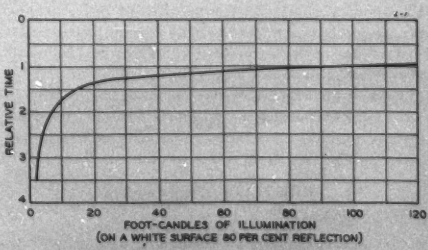

Figure 1. Time and light required for perception

[3] The reader is referred to the sources of these statements for details of the investigators' reasons for arriving at the conclusion that the difference in visibility was the principal cause of the increase in fatalities.

The suggestion may be made that when an industrial plant manager decides to improve the illumination, he may make other improvements as part of the same general program aimed at accident reduction, and that these other conditions may be partly responsible for the ensuing drop in accidents. The experience of the author in connection with over a thousand relighting jobs is that relighting is seldom accompanied by any other change that would affect production, with the exception of changes the lighting engineer may suggest as part of his program for improving visibility, such as painting, changing some machine locations, and tilting surfaces carrying materials undergoing inspection for easier access. In most cases, therefore, the drop in accidents is properly chargeable to the lighting improvement.

The general answer to the question, "What is the relationship between illumination levels and the accident rate?" has been before students of the matter for quite a while, but seems to have been overlooked.

Everyone will agree that if deprived of sight or light and still forced to go about our business we would be certain to have accidents. In other words the relation of visibility to accidents then would be 100 per cent.

Depression experience with reduced street lighting and black-out experience during the war show that accidents average seven times the rate that occurs in the same localities in daylight. That is, under such conditions the accident rate has dropped from the 100 per cent rate with complete lack of visibility to 87½ per cent with slight visibility.

We have here the beginning of a curve showing the relation between lighting levels and accidents, which starts at one end with darkness and all accidents that occur (100 per cent) attributable to lack of light, with the next point on the curve being the amount of illumination somewhere between starlight and moonlight, and an accident rate of seven times the day rate or 87½ per cent.

Now it seems obvious that no amount of light can protect against accidents in which the events move *faster than the speed of vision*, so that the other end of our light–accident curve must be the brightness level at which the speed of vision reaches a maximum. In other words, light as a cause of uncertain seeing can only be a factor in accidents between total darkness and that level of illumination at which speed of seeing ceases to increase. At this point we run into a slight complication. The speed of seeing depends directly on the general or average brightness of the field of view. This average brightness depends, in turn, upon the amount of the illumination present; but, in an interior with dark finishes and dark work materials, the illumination would have to be much more to produce the same speed of seeing that the same illumination could cause in an interior with light finishes.

So the end point of our curve is theoretically placed at that brightness level at which the speed of vision reaches a maximum. Practically, this is of small importance as the speed of vision curve has a knee, beyond which it nearly flattens. Past a brightness of 70 foot-lamberts (90 foot-candles on white; see Figure 1), the gain in speed is slight for the rest of the way. Tentatively, therefore, we can end our curve at 70 foot-lamberts.

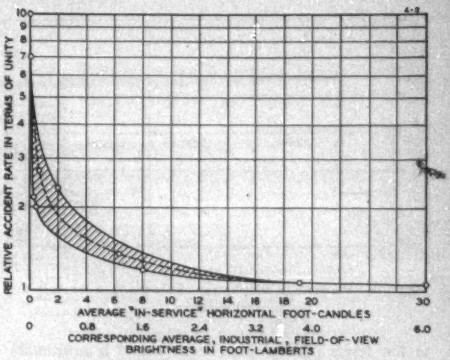
RELATIVE ACCIDENT RATE IN TERMS OF UNITY
AVERAGE "IN-SERVICE" HORIZONTAL FOOT-CANDLES
CORRESPONDING AVERAGE, INDUSTRIAL, FIELD-OF-VIEW BRIGHTNESS IN FOOT-LAMBERTS

Figure 2. Relation of lighting to the industrial accident rate

Unity represents all accidents having a nonvisual cause

Knowing the start of the curve, plus its general downward direction (from traffic statistics), and its probable end, only the in-between shape remains to be filled in. Intermediate points can be plotted from the data in this article in the references. The resulting diagram is shown in Figure 2. It stops at 6 foot-lamberts (30 foot-candles in typical industrial interior), instead of 70 foot-lamberts (350 foot-candles in industrial interiors), as it drops only one of the small squares for a distance of 11 times the width of the diagram, beyond the 6 foot-lambert point.

Lighting engineers will note the inverted resemblance of the median line of this diagram to the speed of vision curve. The speed of vision increases rapidly at low levels of brightness. Conversely the rate of accidents decreases rapidly at low levels of brightness. The decrease in accident rate at higher levels slows down just as does the speed of vision.

In basing this diagram on foot-lamberts, the author has made the assumption that the industrial cases reported by investigators concerned plants that had average industrial interior light reflection conditions. The author has determined from a sampling of industrial plants that the average brightness is 20 per cent of the average horizontal illumination (the cases varied from 7 to 30 per cent). This assumption does not affect the shape of the diagram, but only the location of the foot-lamberts reading along the bottom line.

A casual reader may be tempted to judge from the diagram that accidents owing to lighting are only serious at low levels of illumination, but this would be a misreading of the facts. The accident rate is more severe

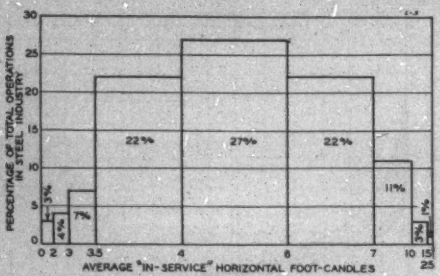

Figure 3. Percentage distribution of illumination levels in the steel industry

at low levels than at high levels but it is sufficiently serious throughout most of the range in which lighting is a factor, to warrant attention.

However, this does raise the question of just how serious "lighting" accidents are, in general, in industry. To answer this question we must know first how lighting and the corresponding brightness levels are distributed throughout industry. We need this knowledge. The writer has had access to such figures for the steel industry. They are plotted in Figure 3, and show for example, that 27 per cent of the operations in the steel industry are performed at illumination levels of from four to six foot-candles, in-service illumination. (This may seem low to the average illuminating engineer, but it is a 100 per cent advance over the comparative figures of nine years ago.) These figures represent lighting installations designed to give from 8 to 15 foot-candles. The difference between the measured and the designed illumination levels is owing to the effects of poor maintenance plus deterioration of the lighting systems. The relative brightnesses are of the order of 20 per cent of these figures.

Looking farther we find that 71 per cent of all steel operations occur at in-service levels of from 3.5 to 7 foot-candles; so it is clear that actual practice, in this industry, at least, is down on the part of the curve in Figure 2 where the accidents caused by lighting conditions are probably from 32 to 60 per cent of the accidents from all other causes. These are serious probabilities.

Pursuing the analysis, a curve can be derived from Figure 2 that will show accidents caused by poor visibility, as a percentage of total accidents, throughout the range of the effect of light. This is given in Figure 4 for the most important part of the range. By a comparison of the data in Figures 3 and 4, the probable net percentage of accidents that had a lighting cause, in the steel industry, in 1942, can be computed (see Table I).

That is, the portion of the total accidents in the steel industry, occurring under artificial lighting, that can be probably attributed to uncertain seeing conditions during 1942 is around 29 per cent. This is surely a serious probability, and as we can expect to find a higher figure in industries that are not so well lighted as the steel industry in 1942, the size of the task that confronts the illuminating engineer begins to loom in its true dimensions.

There is another important aspect to this matter. There were 1,600,000 "loss-of-time" accidents to workers, at work, in 1941, according to the National Safety Council. It is customary to record "loss-of-time" accidents on the basis of whether the worker has to go home (or to the hospital) or not. If his injury is such that he can stay at his post, whether he can do effective work or not, it is not customary to list the accident as a "loss-of-time" accident. Neither are accidents to machines, which also interrupt production, listed as "loss-of-time" accidents. Therefore, when we read that 3,000,000,000 man-hours were lost in the 11 months following Pearl Harbor, we are reading only part of the story.

Uncertain seeing conditions are just as effective a cause of "non-loss-of-time" accidents as of admitted "loss-of-time" accidents. It is a fair prophecy that the provision of certain-seeing conditions throughout industry would save at least 200,000,000 man-hours per year, to say nothing of 4,000 worker's lives and 29,000 cripples, 25 per cent of the recorded "at-work" loss.

In conclusion the author wishes to emphasize that the deductions, diagrams, and curves in this article are only educated guesses (with the exception of the speed

Table I. Percentage of Light-Caused Accidents in Steel Industry

Percentage Taken from Lighting Levels of Figure 3		Corresponding Percentage Accident Rate from Figure 4	Resulting Percentage of Total Accidents
Foot-Candles	Percentage		
0–2	3	46	1.38
2–3	4	42.5	1.7
3.5–4	22	37	8.15
4–6	27	31	8.4
6–7	22	25.5	5.6
7–10	11	20	2.2
10–15	3	12.5	0.4
15–25	1	7.5	0.07
Total			28.9

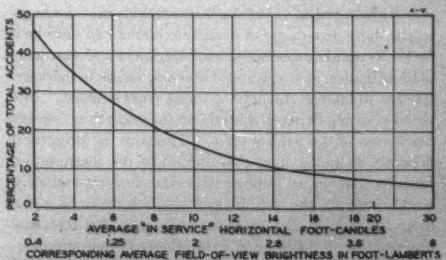

Figure 4. Accidents attributable to lighting causes shown as a percentage of total accidents over the range in which lighting conditions are a cause

of vision curve), but he believes that future statistics will confirm them, and hopes that this study will inspire others to produce the necessary confirmation.

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Three Medals Presented at AIEE Meeting

PRESENTATION of three of the highest engineering honors—the Edison, John Fritz, and Hoover Medals—to three engineers in vastly different fields of the profession, at a special session of the AIEE national technical meeting on January 27, 1943, was unique in the history of the Institute. Research has revealed that at no time previous to this have three such signal honors been conferred at one AIEE ceremony. The 1942 Edison Medal, highest award of the AIEE, was presented to Edwin Howard Armstrong, professor of electrical engineering, Columbia University, New York, N. Y. Willis R. Whitney (A '01), vice-president in charge of research, General Electric Company, Schenectady, N. Y., was awarded the 1943 John Fritz Medal, given for notable scientific or industrial achievement. The award of the 1942 Hoover Medal, honoring an engineer for distinguished public service, was made to Gerard Swope (F '22), president of the General Electric Company, New York, N. Y. Text of presentation addresses and responses of medalists follow (*EE, Mar. '43, pp. 116–17*).

E. H. Armstrong—Edison Medalist

ALAN HAZELTINE, Fellow AIEE

IF we review the advances in electrical technology in the past 25 years, one development stands out from all others, electronics, and specifically the application of the three-electrode vacuum tube. It is appropriate to recall here that the original electronic tube was the two-electrode tube of Edison, in whose honor the Edison medal was established. Others subsequently applied this "Edison effect" in radio detection and introduced the control electrode, but the action was viewed as that of a trigger, as in the modern thyratron, which is of limited application. The real foundation for the unlimited development which we have witnessed was laid by the Edison Medal recipient, Doctor Edwin Howard Armstrong, in an article published in the *Electrical World* in December 1914. Here the common engineering tool, the characteristic curve, was employed for the first time to show how the tube amplifies; and the theory was substantiated by oscillograms which Armstrong had taken. The previously mysterious action of the tube as a rectifying detector with a grid capacitor was elucidated in the same way.

I well remember the impression this article made upon me at the time, and the conviction that here was something with great possibilities. I also remember the excitement produced a few months later by Armstrong's first paper before the Institute of Radio Engineers on his feed-back circuit, which employed this theory to give undreamed-of amplification of weak radio signals and permitted the general use of heterodyne reception by providing for the first time a source of continuous oscillations of frequencies as high as any then used for radio

Alan Hazeltine is professor of physical mathematics at Stevens Institute of Technology, Hoboken, N. J.

transmission. May I take this occasion to note that these publications of Armstrong started my own work in radio and profoundly affected my subsequent career, as they have affected the careers of many others?

It is rather hard now to take ourselves back to conditions in radio prior to Armstrong. Attempts were being made at transoceanic telegraph communication, but with only very restricted success, even with enormous receiving antennas and elaborate commercial apparatus. The radio amateurs, who shortly were to be the mainstay of Signal Corps and Navy radio in World War I and were later to supply the radio engineering talent called out by broadcasting, could receive only local signals. Armstrong's work removed the barrier to regular long-distance radio telegraphy. By increases in power of the vacuum tubes, it also provided an easily modulated high-frequency source for radiotelephone transmitting, so that long-distance radiotelephony soon followed. And then came the great broadcasting development with its far-reaching social consequences.

The early work of Armstrong, the experimental part of which was done while he was still an undergraduate at Columbia University, soon received recognition. Its importance was appreciated by Professor Pupin, who took Armstrong under his wing. Together they carried on several researches in radio. In 1917 the Institute of Radio Engineers awarded its Medal of Honor to Armstrong for the feed-back circuit, the presentation being made by Professor Pupin, then president of that society. I recall a remark of Professor Pupin on that occasion: that inventions are sometimes ascribed to luck, but that the best luck is to have a good head on one's shoulders! The correctness of Pupin's appraisal has been demonstrated amply by Armstrong's subsequent career.

In this period, the question of amplification due to heterodyne reception was in dispute. Armstrong clarified the matter in a paper presented to the Institute of Radio Engineers in 1916. Doubtless this study paved the way for Armstrong's next important invention, the superheterodyne receiver, although Armstrong himself attributes it to the luck of a chance conversation in which were pointed out the limitations to the amplification feasible at the higher frequencies. Armstrong changed the wave frequency to a lower intermediate frequency by heterodyne action, using his vacuum-tube oscillator, and then carried out further amplification at this intermediate frequency. This method was developed for military purposes during World War I, while Armstrong was an officer in the Signal Corps in France. Now it is employed almost universally in radio reception.

Armstrong never abandoned his first love, radio. After the war, he returned to his laboratory researches at Columbia; and here, in an experimental set-up for another purpose, he happened to notice an extraordinary amplification of a locally generated signal. Ninety-nine out of one hundred experimenters would have failed either to notice the effect or to find its cause. But Armstrong's characteristic persistence and ability to analyze physical phenomena tracked down the demon; and superregeneration was added to the radio art. Although it was not of such wide utility as Doctor Armstrong's other fundamental inventions, it was found essential in pioneer work at ultrahigh frequencies and now is applied to certain military purposes.

By this time, we were in the era of broadcasting. Some of the best analytical brains had been directed to the theory of radio. It seemed that all the foundations had been laid, that no new fundamental methods were to be anticipated. Frequency modulation had been considered, used to some extent, and then discarded. The fallacy of using it to narrow the band of transmitted frequencies had been exposed. It was rejected as useless and even harmful. But Armstrong had other ideas. By going contrary to accepted notions and greatly widening the range of frequency variation, he developed a system of frequency modulation ideally suited to broadcasting, which was announced only in 1936. Although

AIEE Edison Medalists

1909	Elihu Thomson	1927	William D. Coolidge
1910	Frank J. Sprague	1928	Frank B. Jewett
1911	George Westinghouse	1929	Charles F. Scott
1912	William Stanley	1930	Frank Conrad
1913	Charles F. Brush	1931	E. W. Rice, Jr.
1914	Alexander Graham Bell	1932	Bancroft Gherardi
1916	Nikola Tesla	1933	Arthur E. Kennelly
1917	John J. Carty	1934	Willis R. Whitney
1918	Benjamin G. Lamme	1935	Lewis B. Stillwell
1919	W. L. R. Emmet	1936	Alex Dow
1920	Michael I. Pupin	1937	Gano Dunn
1921	Cummings C. Chesney	1938	Dugald C. Jackson
1922	Robert A. Millikan	1939	Philip Torchio
1923	John W. Lieb	1940	George Ashley Campbell
1924	John W. Howell	1941	John B. Whitehead
1925	Harris J. Ryan	1942	Edwin H. Armstrong

facing the tremendous handicap of an established broadcasting system, with thousands of transmitting stations and many millions of receivers in use, none of which could employ it, it already seems destined largely to supplant the conventional amplitude modulation. The two great limitations in amplitude modulation were the noise accompanying the signal and the interference between stations on neighboring frequencies, so that over a large area two stations would spoil each other's programs. Wide-range frequency modulation enormously improved the signal-to-noise ratio and almost eliminated the area over which stations on neighboring frequencies would interfere. Besides, the use of ultrahigh frequencies, essential in this system, made it feasible to cover a wide audio-frequency range, with great improvement in the fidelity of reproduction.

Of course, Armstrong has made many other discoveries and inventions. Specific oscillating circuits commonly associated with other names were among those which he was the first to study. In his early work with Pupin, he considered a regenerative vacuum tube as a controllable negative resistance or reactance element; and he made laboratory measurements of these properties. But the time was not ripe for the present-day applications such as automatic tuning.

Not only has all of Armstrong's work been built on the electronic vacuum tube originating with Edison, but his most evident characteristic has been that for which Edison was famous—pertinacity. I can testify that mealtime means nothing to Armstrong when his mind is set on a technical matter; this must be settled first, even though an after-dinner discussion would have been as effective! But it is just such concentration that has been needed to carry through his discoveries and developments.

There is another characteristic of Armstrong which is not so immediately evident: He is mathematical, because all of his results, no matter how he was first led toward them, were ultimately put in logical exact form. He is not known for the discovery of new scientific facts, nor for the creation of new structures. His discoveries were methods—new ways of doing things. Let us draw a parallel: The true father of electrical engineering was Faraday, who laid a new foundation for every branch of electrical science and whose concepts are the working tools of the electrical engineer. Because no algebraic equations appear in Faraday's writings, he has been viewed simply as an experimental physicist. But Pupin, appreciating the exactness of Faraday's reasoning, has pronounced him a great mathematician. It is so with Armstrong, who shies when you talk to him with equations, but who reasons clearly and accurately in the many-dimensional field of physics, rather than in the one-dimensional field of algebra and calculus. It may be significant that in Pupin's old office, which Armstrong now occupies, there hangs one picture each of the famous pioneers of electrical science, but there are two pictures of Faraday. Armstrong also is an inspired mathematician.

Vagaries and Elusiveness of Invention

EDWIN H. ARMSTRONG

IT is not possible for me to find the words to tell you what this honor means to me. To have belonged to the generation which learned the meaning of volts and amperes when Edison was at the height of his career, to be able to follow in the footsteps of my old instructor—Michael Pupin—who stood here 22 years ago, and to have my own work appraised, during these difficult days, as worthy of the Edison Medal, gives it an inspiring meaning that can never be described.

But on an occasion such as this, when a man looks back over the events associated with his work, there come some sobering second thoughts. For he begins to realize how minor is that part which he himself has played in shaping the events of his career, how overpowering the part played by circumstances utterly beyond his control. The continuous good fortune which has followed me, providing second chances at inventions when the first chance was missed and tossed away, has been all that a man could hope for and more than he has any right to expect.

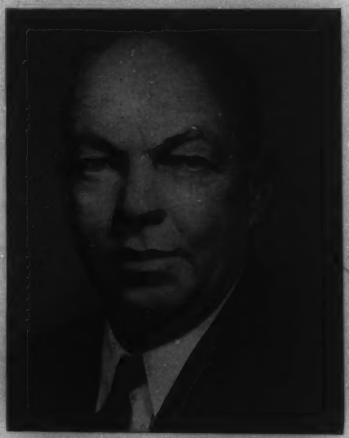
Only the invention of regeneration and the system of frequency modulation were the result of any conscious effort on my part to solve a definite problem. One problem was attacked on no theory at all except that something must be wrong with the existing one; the other problem was attacked by a method of reasoning that was to turn out to be just 100 per cent wrong. And in each case, a chance observation in the laboratory was to lead to the discovery of principles the existence of which I never had the remotest idea.

These occurrences, however, must be considered as the outgrowth of quite ordinary and conventional research in the light of the chain of circumstances which were to lead to the discovery of the superheterodyne and superregenerative principles. One of these was to come from a war, the other from a legal proceeding.

I am most highly flattered by the reference which my good friend, Alan Hazeltine, has made to any ability of mine in the realm of the mathematical way of thinking. The fact is that the first step in the chain of events which was to lead to the superheterodyne invention came about because I could not understand the mathematics used in the dispute he has referred to, and I had to make

a long experimental investigation to clear it up. This investigation gave me for the first time a clear understanding of the nature of the heterodyne. These results were published shortly before I left for France for service in the Signal Corps in the American Expeditionary Forces.

Shipped via England, I arrived in Southampton, and there came the second link in the chain of good fortune. Bad weather was to close the English Channel for three days and give some of us the opportunity to go to London and see the town. There I chanced to meet Captain Round of the British Army Intelligence Service and from him learned of one of the most important problems of the war, the reception of very weak signals of what then were considered to be "short" wave lengths. He outlined the highly ingenious steps which already had been taken along conventional lines, but as they involved the use of special vacuum tubes which we did not have, it was clear that the problem as far as the United States forces were concerned was one for the base laboratories. The information was duly forwarded to the United States.



Edwin H. Armstrong, 1942 Edison Medalist

The third link came months later as I happened to be watching a night bombing raid and wondering at the ineffectiveness of the antiaircraft fire. I may say that night bombing was not very dangerous in those days, either for the man on the ground or the man in the airplane. Thinking of some way of improving the methods of locating the position of the airplanes, I conceived the idea that perhaps the very short waves sent out from them by the motor ignition system might be used. The unique nature of the problem, involving the amplification of waves shorter than any ever even contemplated and quite insoluble by any conventional means of reception, demanded a radical solution. All three links of the chain suddenly joined up and the superheterodyne method of amplification was practically forced into existence. Not one link in the chain could have been dispensed with. This, I think, is the only completely synthetic invention I have ever made.

The superheterodyne was never used in World War I for the purpose for which it was invented. A more important use for it then was found. But it is interesting to note that it is one of the indispensable elements of an aircraft-detection scheme of the present war which operates on a much more practical principle.

Seldom can an inventor look philosophically upon the bane of his existence, patent litigation, and find much good therein. He might as well be expected to become philosophical about the serpent in the Garden of Eden. Yet the superregenerative circuit was to be discovered as a direct result of a legal action in which the regenerative circuit became involved shortly after World War I. During these proceedings it came to pass that counsel for the opposition made denial of some fundamental truths. Such behavior is not entirely unknown in courts presided over by even our most learned judges, nor can it be said to be entirely unsuccessful.

To furnish a convincing answer, I set up demonstration equipment involving some measurement apparatus that included a regenerative circuit. These instruments were all placed on a table in the Marcellus Hartley Research Laboratory at Columbia University and arranged to receive from a miniature transmitter across the room, and were quite dissociated from any antenna or ground connection. While I was adjusting the receiver to respond to signals from the miniature transmitter, other signals of a most unusual character suddenly came in. The first thought was that a British cruiser was nearby in the North River, since the tone of the telegraphic signal was somewhat akin to their characteristic double-tone spark note and the strength so remarkable. It was then observed from the character of the messages that the signals were coming from the Brooklyn Navy Yard. Other well known stations also came in with a strength hundreds of times that which any regenerative circuit would give. As it gradually dawned upon me that some new principle of amplification was being observed, the nature of which I could not even guess, the effect disappeared and could not be reproduced. Only the comparatively feeble response of a simple regenerative circuit was left, and nothing I did would make it behave in other than its quite conventional manner.

Five minutes before I would have sworn to the high heavens that I understood all there was to know about regeneration. Five minutes only were required to wipe out that complacent belief engendered by nearly a decade's work with the subject. Some completely bewildered experimentation eventually restored the strange effect,

and finally I learned how it could be maintained long enough to examine it. And then it only remained to find out what it was all about and discover the principle of operation. A little work brought to light a principle quite beyond the bounds of one's wildest dreams. Its existence had never been suspected, in any way and it is doubtful if it could ever have been evolved by analytical means. Professor Hazeltine, who helped me over the high spot in one of the obscure phases of this theory, will, I think, bear me out.

Much of what I have said is already well known, but there is one chapter in the history of superregeneration which has never been published. It was not known to me until a few years ago.

Five years before the events which I have just related took place, I set up and operated what I now know to have been a superregenerative circuit. Because of the particular conditions under which it was used, the superregenerative effect was not manifested outstandingly. I missed it, ascribing the operation of the circuit, which was somewhat better than expected, solely to the effects of ordinary regeneration. The arrangement was published in my original paper on regeneration in 1915, described as a regenerative circuit, and the paper was translated into many languages and went to the four corners of the globe. No one apparently saw anything more in it than I. Nearly 20 years later, while looking idly through this old paper, recollection of some of the effects observed brought the startling thought that I must have then had and missed superregeneration. The original apparatus, which was still intact, was set up and put into operation again and it superregenerated beautifully! It is seldom that one avoids the penalty for a blunder such as this.

I have related here a story of events that good fortune alone could bring about, but I do not want to create the impression that one's guardian angel always acts so promptly. The chance observation in the case of the frequency-modulation system was delayed for nearly 20 years while a course of what I, at least, considered reasoned effort led to a chase of more will-o-the-wisps than I ever thought could exit. It takes a long time to learn the lesson that reasoning sometimes cannot give the answer.

There has grown up through the years a school of thought that is coloring some of the recent legislative proposals dealing with invention, which holds that invention can be reduced solely to a basis of logic and reasoning. I wish I could persuade them to explain to me the system; it would save an enormous amount of trouble. I have never been able to do it, except afterward. For the disciples of that school I would suggest just a few years apprenticeship in a laboratory, working on what we would today term an "insoluble" problem. Daily contact with the laws of nature has a way of keeping a man's feet on the ground.

I have tried to describe the effect that circumstances quite out of my control had to do with the making of these inventions. I wish it were possible to describe here also that part played by my old instructors and those who have assisted me through the years. Here also I have had extreme good fortune. For the moment I can only echo the thought expressed by the recipient of the Edison Medal last year, that he wished the names of those who had helped him attain it could be engraved upon it, and say that whenever I look upon this award, I shall always see their names around it.

Willis Whitney—John Fritz Medalist

DAVID C. PRINCE, Fellow AIEE

IF you should pick up a turtle five miles or so from Schenectady, N. Y., and find markings on his shell —a date and the letter *W*—you would note the time and place of your discovery and notify Doctor Whitney; you and the turtle then would be participating in scientific research. Down on the island of Nassau there are conch shells that show markings and pictures through their opalescent linings. They have been in Doctor Whitney's hands and he has made these markings to study the mechanism of shell growth.

I suppose as a boy in Jamestown, N. Y., he poked around the beaches of Lake Erie and the neighboring woods, picking up sticks and stones and throwing them at trees or in the water. Then he came to know Mr. William Hall, a neighbor. Mr. Hall was a naturalist as well as a businessman. He had a microscope and made his own slides. He showed these to the boys in the evening after school. A new world was opened to Willis Whitney. Things were not what they seemed to the naked eye. They had fine-grained structure. Why?

The Whitneys gave Willis a microscope of his own. He made sections and tried to find out for himself how the world was made.

He went to the Massachusetts Institute of Technology in 1886 to learn more of the composition of nature. Biology, electrical engineering, and chemistry all attracted him. He chose chemistry but his curiosity has never been confined to a narrow beam. Biology and physics have shared his interest in chemistry and anything else that came before him.

He went to the University of Leipzig to study under Wilhelm Ostwald. There he received the degree of doctor of philosophy. He studied for a short time at the Sorbonne under Charles Friedel. Then he returned to Massachusetts Institute of Technology to teach and investigate on his own account. Gerard

David C. Prince is vice-president in charge of application engineering, apparatus department, General Electric Company, Schenectady, N. Y.

Swope was one of his students.

He found that rusting was produced by iron going into solution in pure water by replacing hydrogen ions which are deposited as gaseous hydrogen on the metal. If oxygen is dissolved in the water it reacts with the hydrogen, removing it from the surface and allowing the rusting to proceed. He experimented with other phenomena and declined offers of jobs outside the Massachusetts Institute of Technology because he feared they might restrict the opportunities for research.

In 1900, Mr. E. W. Rice, vice-president of the General Electric Company thought of forming a research organization for the company. He reasoned that the electrical industry was based on the discoveries of scientists like Faraday and Maxwell, that more discoveries were sure to follow, and that the growing industry should have the benefit of them.

Other industries had laboratories. They tested materials to be sure that they came up to specifications. They were called in to investigate unexpected difficulties but they did not investigate the unknown as such. Mr. Rice wanted a laboratory to carry on research in pure science. He invited Doctor Whitney to organize such a laboratory.

In spite of Mr. Rice's assurances, Doctor Whitney feared that he would not be free to select his own subjects of research, he questioned whether there would be enough worth-while problems in the electrical industry.

Finally after consulting Professor Elihu Thompson, Doctor Whitney agreed to work part time in Schenectady, associated with Doctor Steinmetz. Doctor Steinmetz was showing how the work of Faraday and Maxwell could be interpreted quantitatively in the design of actual motors and transformers. Doctor Whitney shared an assistant and a barn behind Steinmetz's house for three weeks until the barn burned. Then he was assigned a small building in the factory and the research laboratory was born, although it was not until 1904 that Doctor Whitney was satisfied that it offered him a full time job.

In the early days of the research laboratory Doctor Whitney did most of the work himself. The metalized carbon filament, first big advance in incandescent lamps beyond the point reached by Edison, was made by Whitney. He developed ceramic-type high resistance rods for early lightning arresters and arc electrodes. Other scientists—Coolidge, Langmuir, Hull, and many others—were attracted to the laboratory. Doctor Whitney continued his own researches but was always glad to turn over a good lead to one of his younger associates who would get all the credit for any good that came of it. For all of them he maintained a friendly atmosphere in which apparatus and free advice and interchange of ideas were encouraged.

Outside scientists visited the laboratory constantly and were introduced to the laboratory staff through colloquia where developments inside and outside the laboratory were freely exchanged. Publication of all scientific findings at an early stage was always encouraged. Doctor Whitney believed that for every idea he gave away he would get two back.

It may seem a far cry from the wanderings of turtles to Langmuir's investigations of monomolecular layers but the fundamentals are the same. An observation is made, an hypothesis is constructed. Tests are initiated to prove the hypothesis or serve as the basis for a new hypothesis. It may seem a far cry from sharing one assistant and a barn with Doctor Steinmetz to sharing the facilities of a great laboratory with a hundred staff members and scientists of the world at large, but again the principle is the same.

In recognizing the value of the combination of these two elements so essential to our modern world, the John Fritz Medal Committee should be honoring both the recipient and the memory of the man for whom the medal is named.

John Fritz Medalists

1902	John Fritz	1925	John F. Stevens
1905	Lord Kelvin	1926	Edward D. Adams
1906	George Westinghouse	1927	Elmer A. Sperry
1907	Alexander Graham Bell	1928	John J. Carty
1908	Thomas A. Edison	1929	Herbert Hoover
1909	Charles T. Porter	1930	Ralph Modjeski
1910	Alfred Noble	1931	Admiral David W. Taylor
1911	Sir William Henry White	1932	Michael I. Pupin
1912	Robert Woolston Hunt	1933	Daniel C. Jackling
1914	John E. Sweet	1934	John Ripley Freeman
1915	James Douglas	1935	Frank J. Sprague
1916	Elihu Thomson	1936	W. F. Durand
1917	Henry Marion Howe	1937	Arthur N. Talbot
1918	J. Waldo Smith	1938	Paul D. Merica
1919	George W. Goethals	1939	Frank B. Jewett
1920	Orville Wright	1940	C. F. Hirshfeld
1921	Sir Robert Hadfield	1941	Ralph Budd
1922	Eugene Schneider	1942	Everette DeGolyer
1923	Guglielmo Marconi	1943	Willis Rodney Whitney
1924	Ambrose Swasey		

Engineering Research

WILLIS R. WHITNEY, Associate AIEE

WHEN I consider the work of the former recipients of the John Fritz Medal, I see clearly that I am not one of those sturdy individualistic pioneers of engineering but rather, a well-protected product of organization, a representative of a group of supported scientific workers. This greatly increases the satisfaction and honor which I feel in this event.

After many years as director of research, I realize that usually I did not direct anybody or anything. A director merely points like some wooden arrow along the highway. Research directing is following the openings of acceptable new ideas. It is watching the growth of thought in the minds and hands of careful investigators. Often even the lonely mental pioneer, being grubstaked, advances so far into the generally unknown, that a so-called director merely happily follows the new ways provided. All new paths both multiply and divide as they proceed, so with much random direction there would be danger of getting lost.

During the major period of American enterprise, the engineer was not only the discoverer of new needs, he was forced to be also the experimenter, developer, and procurer of necessary financial support. Such have been most of the eminent recipients of the John Fritz Award. Anyone knowing the pioneering engineers of our early days, knows many who suffered privation and made all sorts of sacrifices to promote their ideas. There was no way of knowing the promise of some novel idea or of some energetic engineer.

Willis R. Whitney, 1943 Fritz Medalist

As industries expanded with the growth of the United States, engineers became regular employees of the large organizations. The works of mining companies, railroads, city and federal governments, and manufacturing in general were directed by permanently employed engineers. As engineers increased in number in scientific societies and individual industries, the helpful effect of one mind on another, the group support, became evident. Then the risk of new undertakings was reduced, so that large organizations could advance safely. As a result of the expansion of industries so that thousands of employees were concerned, the danger of product obsolescence became acute, and there was the threat of large numbers being thrown out of employment by some improvement in the industry. All engineers aimed at newness and product betterment, and so anyone might suddenly disrupt a group of workers by some alteration of product or process.

The research laboratory of the General Electric Company was a development of the idea that large industrial organizations have both an opportunity and a responsibility for their own life insurance. New discovery can provide it. Moreover, the need for such insurance and the opportunity it presents, rise faster than in direct proportion to the size of the organization. Manufacturing groups could thus develop their continuity beyond that of the originator, because the accumulated values of knowledge and experience became gradually recognized. No one yet knows the possible longevity of a properly engineered manufacturing system. Research has become engineering support.

Research is expensive. No one knows exactly how much an industry should spend on research. Clearly, a small, one-product company could scarcely afford even a full-time researcher; yet individual and small companies have been successful. Emerson's mousetrap comes to mind. Certainly the fellows who still make the red-stained, four-hole, wooden mousetrap must have sought new knowledge so that after so many years it can still hold its own.

I once looked forward to trying to get the General Electric Company to expend regularly one per cent of profits on the pure science. I look back and wonder why I ever aimed so low. I have such confidence in the still unknown, such faith in American curiosity, and such a conception of the exponential possibilities of new efforts that I would temporarily greatly reduce dividends in order further to insure permanence.

I sometimes think poets express truth better than scientists do. In the "Testament of Beauty" of Robert Bridges, formerly poet laureate of England, are these words: "Conduct lies in the masterful administration of the unforeseen."

Our industrial "unforeseen" is made up of new liabilities and new assets. What we don't yet know, we must still administer masterfully if we want to survive. It may be contradictory to use the "unforeseen" in illustrations. But old facts may be extrapolated. A live industry is always engineering new or better products.

The General Electric Company's laboratory of scientific research was established by the voice of engineers under the leadership of their chief, E. W. Rice in 1900.

I think he felt that the new electrical industry could be unlimited if proper foresight were used. He also saw that at any one instant all the engineers were absorbed by pressing calls, trouble shooting for improvement and economies of established products. There should be an incubator of unborn ideas to be generated by discoveries in the purely scientific core of electricity. Thus aid would be given engineers, through the electrical curiosity of experimenters in any part of the field. He hoped to keep his electric company co-operating even if the demand ceased for some of its current products.

He wanted actual search for new truth about electricity and so introduced to cost of production a new kind of industrial overhead. Discoveries were not merely desirable end points, but were starting points in an infinite field of electrical service. The process could be self-perpetuating. We have all witnessed ends of many profitable undertakings in electricity where the recovery of commercial activity was successfully cultivated in quite new electrical fields. Such activity as production of carbon incandescent lamps, carbon arc lamps, and so forth, peacefully passed away without excessive hurt. Some unforeseen undertakings in electronics could provide the cure.

At no time in history was there such a great mass of the "unforeseen" available to us. This applies to every bud and tip of countless branches in the forests of trees of knowledge. These can never die and they await appreciation.

I have thought of this in connection particularly with modern chemistry and the new electricity, but it applies as well to all our mental activities. We still fail to realize our possibilities.

The experience of organic chemistry was repeated in electrical science. The new field seems infinite again. There is room enough here for a world of scientists. Certainly some of the slack of postwar depression may be taken up through new knowledge.

I have lived to see that bothersome "Edison-effect" of vacuum lamps develop into the boundless areas of electronics. Hard, round, indivisible atoms, of centuries' endurance, began to emit some of their components. Nothing could have been more "unforeseen" than that. And now photographs of some of those organic chemical molecules are actually made without light, by electrons which give us a magnification scores of times higher than was ever optically possible. The wildest imagination never foresaw what has actually come from this truly "unforeseen."

In summarizing advances in practical electronics, I like to compare the electron with Archimedes' lever. Electrons do their work by using imaginary dimensions and almost nothing for the levers. The length, the fulcrum, and the material have disappeared. Disembodied electrical power itself is guided by unhuman electrical senses. Resembling our human senses, they are much more exact and tireless. The power of screws, the use of wheels, hydraulic rams and presses, pulley blocks, belts and trunnions, and races of ball bearings came directly from the principle of the lever. Certainly one could lift the world if a fulcrum were ready. Perhaps the same should be said of the electron. Employed first for speaking, hearing, seeing, smelling, tasting, and feeling, it can record its findings and it can also present its records at any time in any part of the world. It can use a subconscious integrating entity for directing and controlling any amount of power while performing any kind of work at any desired rate.

The strange thing about it is that this is all done, not by "mirrors," but by next to nothing in a vacuum.

Electronics seems to me as extensive and promising a new science as the whole of electricity seemed but a few years ago.

Gerard Swope—Hoover Medalist

KARL T. COMPTON, Fellow AIEE

GERARD Swope is presented for the Hoover Medal on the ground of his "constructive public service in the field of social, civic, and humanitarian effort." One of his humanitarian efforts has been to help me on many occasions in the consideration of measures for improving the educational work of the Massachusetts Institute of Technology, of which he is an executive committee member.

I attempt to summarize some aspects of the constructive public service for which this medal is awarded with some misgiving as the result of a dinner conversation which I had last night with the head of one of the divisions of the General Electric Company. He told me that the first thing which struck him about Gerard Swope was his impatience at having to waste valuable time listening to statements about matters on which he was already informed.

As the setting for the particular achievements recognized by this award, turn briefly to Gerard Swope's engineering and business career. It was two years before his graduation in 1895 as an electrical engineer from the Massachusetts Institute of Technology that he was first employed by the General Electric Company in the humble rank of "helper." At the Massachusetts Institute of Technology one of his instructors was Doctor Willis R. Whitney. I had a very interesting letter from Doctor Whitney apropos of this occasion, in which he described his very favorable impression of Gerard Swope as a student, and his equally favorable impression of Gerard Swope as his chief later on. As a student he remarks that, as he recalls it, Gerard Swope was not one

Karl T. Compton is president of Massachusetts Institute of Technology, Cambridge.

of the group which attached the compressed air to the gas mains. As a chief, he remarked that looking back on the efforts which he had made and the many discussions he had had with Mr. Swope in regard to the increasing of the research facilities of the General Electric Company, he was inclined to feel that any lack of securing even more support than he did secure was due to his lack of imagination and failure to present the case rather than to any withholding of support by his chief.

Hoover Medalists

1930	Herbert Hoover
1936	Ambrose Swasey
1938	John F. Stevens
1939	Gano Dunn
1941	D. Robert Yarnall
1942	Gerard Swope

After graduation from the Massachusetts Institute of Technology, he went to work in the shops of the Western Electric Company and shortly thereafter became manager of the branch in his boyhood home city of St. Louis, Mo. Then after two years in the Chicago (Ill.) Division, he came to New York as general sales manager of the company in 1908, and five years later he became vice-president and director.

In 1919 he left the Western Electric Company to become president of the International General Electric Company. A sentimentalist might say that this was going back to his first love and suggest that it was the consummation of day dreams which may have passed through his mind during his career as helper 26 years earlier with the General Electric Company, but I have heard a much more realistic explanation from one of his former colleagues in the Western Electric Company to the effect that Swope so outgeneraled his General Electric competitors year after year that, unable to beat him, they had to elect him their own president.

However this may be, he became General Electric Company's president in 1923, resigning from this position in 1940, but he was called back to it in September 1942 in order that his successor, Charles E. Wilson, might accept the vice-chairmanship of the War Production Board.

His career as electrical engineer, commercial engineer, and industrialist has brought him distinction and a good living. But in so far as the Hoover Medal is concerned, this industrial career has given setting and opportunity for what we in academic circles call extracurricular activities—activities which go beyond the minimum requirements of the job, though usually constructively related to it. Therefore, I am going to suggest some of the present medalist's interests which are typical of those for which the Hoover medal is awarded.

In the field of economic leadership little need be said. Though of very great significance, Gerard Swope's accomplishment in this field is obvious. The administration of a great industrial organization in such manner as to give the public more and better services and products at less cost, to build up the loyalty and self-respect of the members of the organization, to satisfy the stockholders, to inaugurate policies designed to stabilize the business through good times and bad, yet flexible enough to meet new situations successfully; to be ever on the alert to seize opportunities for technological or social improvement—such administration in itself is economic leadership of high order. Such leadership Gerard Swope has displayed throughout his career.

I think the basic reason for his success in this field is disclosed in a comment by the one who knows him best, his wife. She remarked that, "He has always thoroughly respected his job, . . . believing that industry, which touches so many lives, is a most important part of our society."

I can do no better in introducing the next comments than again to quote Mrs. Swope, at the same time mentioning that she has shared his intense interest in humanitarian affairs ever since they first met in connection with the activities of Hull House in Chicago and under the influence of Jane Addams. Mrs. Swope has told me that her husband "has always been more interested in civic and social projects and aims than in the purely philanthropic which, rightly or wrongly, seem to him less constructive."

I have, myself, observed his keen combination of hard-headed practical good sense and altruistic purpose. For example, he has long had a strong desire to help deserving young people to secure an education. But he does not approach this by the easy way of giving them money, except perhaps as an occasional incentive in the form of a prize. He has also been concerned with the financing of educational institutions in which he has been interested, but again his normal approach is not in the easy and limited manner of a gift. Instead, for example, he combined all these objectives in a constructive manner by raising a large loan fund, available to deserving students and administered in businesslike fashion so as to be perpetually revolving. This aids the student, justifies the institution in charging a substantial tuition, and hence aids the institution, and yet is devoid of the element of charity. Except for the original donors of the fund, it is a strictly business proposition on all sides, payment for value received but under most helpful circumstances.

On a much more important scale, these same principles were embodied in Gerard Swope's very important contributions toward the solution of problems of unemployment and stabilization of industry. On these problems he worked with great zeal and effectiveness, especially during the early 1930's when the public was generally bewildered by the tragedy of the depression. Characteristically thinking ahead of the majority of his

fellows, he was ready with constructively thought out proposals, and by his leadership and stimulation, did an enormous service in helping to mold the thinking of businessmen, labor leaders, and the general public.

This industrial relations situation is complicated by forces of prejudice, politics and selfishness, as well as of scientific logic. It is not strange, therefore, that the Swope plan of unemployment insurance or the Swope plan of industrial stabilization have not been adopted just in the form in which he proposed them. Yet it is certainly fair to say that the plans now in force under such auspices as, for example, the Social Security Act, are far better plans than we would have had except for the ideas and stimulus contributed by Gerard Swope. Also, all through the ranks of industry, labor, and government are officials whose sympathetic understanding of problems of employer–employee relations and industrial stabilization is based directly or indirectly on the organized thinking of which his contributions were so significant a part.

But to get back to Swope's basic attitude in these matters, take the case of unemployment benefits. He did not like any system of doles or handouts, either from industry to its workers or from government to its citizens. He believes that such expedients are not only not constructive, but that they are positively demoralizing. But he does believe in giving help generously where the person helped co-operates in the effort, and provided it is done in such manner as will tend to create conditions reducing the necessity for help in the future.

For example, his unemployment-insurance plan adopted by the General Electric Company provided joint contributions to the reserve fund both by company and employees. Thus, to protect the fund and to reduce the size of their contributions to it, both parties have a financial incentive to run their affairs so as to keep unemployment at a minimum. He disapproved a state plan which proposed simply to pool all contributions from employers, on the ground that this would detract from the financial pressure on each individual employer to run his own business as stably as possible, and also on the ground that this would force one employer to pay part of the costs of careless employee management by another.

Thus, throughout Gerard Swope's altruistic idealism, we see a clear pattern of shrewd business judgment and fundamental fairness. This element, combined with his absolute unselfishness and intense desire to improve human society, are, in my judgment, the foundations of his work which have led to the award of the Hoover Medal.

I am conscious of my inability to present here any adequate portrayal of a man of such energetic and varied accomplishments. I have, therefore, tried to give only some scattered glimpses of the man himself. But to suggest how much more remains unsaid, I am going simply to recount a list of some of his public commissions.

Going back to his early days only a few years after his graduation from college, Gerard Swope served on the Playground Commission of St. Louis and was chairman of the Public Bath Commission of St. Louis. Then during World War I, under General Goethals, he was assistant director of purchase, storage, and traffic on the general staff of the United States Army, for which he was awarded the Distinguished Service Medal. Then coming into the times of the early depression, his public services included the following:

Industrial Advisory Board of the National Recovery Administration.

Chairman of the Business Advisory and Planning Council, under Secretary Daniel Roper.

Chairman of Coal Arbitration Board.

President's Advisory Board on Economic Security.

First National Labor Board.

First president of the National Electrical Manufacturers Association.

Advisory Council on Social Security.

Chairman of the Industrial Relations Commission to Great Britain and Sweden.

Chairman, Eighth American Red Cross Roll.

Chairman of the National Mobilization for Human Needs.

Member of the Corporation and Executive Committee of Massachusetts Institute of Technology.

Member of visiting committee of Department of Astronomy of Harvard University.

Past president and director of Greenwich House, New York, N. Y.

Council on Foreign Relations.

President, Westchester County Park Commission.

Taconic State Park Commission.

Chairman, New York City Housing Authority.

Assistant to the Secretary of the Treasury.

Chairman, National Budget Committee for War Appeals.

Excerpts from letters received following the announcement that Gerard Swope was to receive the Hoover Medal further bear out the fact that his choice as recipient was highly merited. The first from Daniel Roper follows:

"I am glad to learn that you are to make the presentation address on the occasion of the award of the Hoover Medal for 1942 to our mutual friend, Gerard Swope.

"Nothing is more interesting and suggestive than the development in man of ethical qualities which prompt leadership for good. Such qualities are possessed in unusual fullness by Mr. Swope and in doing him honor, we honor ourselves.

"The drastic income tax law of 1917, which I was required to administer, brought the Federal Government and industry into partnership. Concluding that both partners should jointly study their mutual problems, I organized an advisory group of business men to co-operate in interpreting and applying the new and complex law. The plan worked so satisfactorily that when I became Secretary of Commerce in 1933, I began a search for outstanding industrialists to serve as a Business Advisory Council for the Department of Commerce. We were very fortunate in securing Gerard Swope as the first chairman of that Council. Under his guiding

hand, there was organized an able and eminent group of business men who, without compensation and at great personal sacrifice, co-operated with the Department of Commerce, the other executive units of the Government and with the Congress, in studying the problems of the depression period, and, later, the grave problems of the defense program of the Government. Assisted by these advanced studies, several of these men are now prominently identified with the war program and are rendering invaluable service to their Government. I cherish with deep gratitude the very valuable guidance given by Gerard Swope as first chairman of the Business Advisory Council of the Department of Commerce."

The following is a letter received from Fiorello La Guardia, mayor of New York City:

"Mr. Gerard Swope's public spirit and willingness to serve the public was well demonstrated when on the day of his retirement, to which he had looked forward for a long time for a much needed rest, I asked him to step in and take the chairmanship of the New York City Housing Authority. I had a problem on my hands. There were millions of dollars in construction or about to commence. There were thousands of families waiting the completion of these low-cost housing units. In typical Gerard Swope fashion he curtailed a planned trip to South America, worked on the ship, came back in a few weeks and assumed his duties. He did a creditable job, a difficult one, and served up to the time that he was called to Washington. The city is in debt to Gerard Swope for his splendid services and is indeed grateful."

Finally, comes a letter from Gerard Swope's closest associate, Owen D. Young, whom I asked for help. Because his reply is so interesting and because he is such a master of the subject under discussion, I am going to take the liberty of quoting his entire letter:

"Replying to your letter of November 30 about Gerard Swope, I should say first of all that I am primarily interested in the over-all picture of a man and secondarily in his accomplishments. The latter are only items of proof, the detail of the picture.

"Starting with his most obvious characteristic, one recognizable on the instant of a first meeting, is his dynamic personality. He is like a spring under tension always, never spent and never relaxed. The next characteristic is his utter incapacity for ambiguity. He can not think ambiguously, and he could not speak ambiguously if he would. As a result of these two qualities, you have force and clearness which are as vital to an effective person as they are to effective speech. Together they are an instrument of penetration like the scalpel or the X-ray, a tool which nature gave him and which has improved progressively with use. It is a dangerous tool which has ruined many men. It is safe only when coupled to industry and anchored to character.

"Gerard Swope is passionately industrious and inescapably devoted to principle. His industry urges him to know more about any subject he touches than others, at least more of the vitals of it. His principle is always an insurance against industry leading him astray.

"What I have said above is true whether he touches engineering or accounting or finance or salesmanship or negotiation in any form. It was true of him as an officer of the Western Electric Company. It was true of his service in the last war under General Goethals and his conspicuous capacity to adapt himself as a civilian to a military regime. It was true of him as president of the International General Electric Company which stretched his geography and his experience with other peoples and other races. He was successful alike with the English, French, Germans, Japanese, and Chinese, to mention only the conspicuous samples. I dare say that it has been true of him as a trustee of your own Institute [Massachusetts Institute of Technology].

"These are the reasons why Gerard has been such a great success as president of the General Electric Company: the determination to understand its sprawling activities, the capacity to relate engineering, manufacture and sales into a single integrated picture, yet with full comprehension of the variables in each of the individual pieces. This means great capacity to deal with things. It would all be useless, however, unless it were intimately geared to a knowledge and understanding of people.

"That is the reason why Gerard did run a great concern without a strike. That is the reason why he was General Electric's most successful salesman. That is the reason why programs of retirement, pensions, savings, unemployment protection, and similar contributions to the welfare of his associates in the General Electric Company, which included every employee, were adopted and made practically effective to the utmost extent that competitive conditions and corporate solvency would permit.

"The problem of making a great concern function for the maximum benefit of employees, stockholders, and the public requires not only the conscience of a trustee, but that clarity of mind and fairness and firmness of decision which prevents any one of the three encroaching on the others. They are all superficially in conflict and all basically unified in ultimate interest. One must have keen human sympathy to do such a job. He must keep his emotions controlled by his intelligence and keep all of them in hand by devotion to principle. That means intelligence, human sympathy, and character functioning at their best.

"Such are the qualities which, to my mind, have made Gerard Swope worthy of the Hoover Medal."

Honored already by medals and decorations at home and abroad and by numerous honorary degrees—such is the man, and the record of the man, to whom the Hoover Medal has been awarded.

The Engineer and Social Development

GERARD SWOPE, Fellow AIEE

THE citation given me is much more generous than my efforts warrant—it is really the reflection of the ideal of the work of engineers for the public good. It is recognized that engineers are dealing not only with material and natural forces but with and for human beings.

This ideal of the engineering societies points the way to a wider opportunity for the engineers to take a greater part in the progress of social development. The foundation of such participation should be a broader and more comprehensive conception of the education of the engineer. Today, we have abandoned the old fatalistic idea that engineers are born and not made, and we now believe that much can be done by training and environment in broadening the scope of the engineer's activities.

The foundation of engineering training is, of course, in the exact sciences, mathematics, physics, and chemistry. The education of the engineer, however, must not be confined to these basic subjects but should include

history of the development of man, his industries, and his relations with other men, as well as the migration and development of peoples, thus leading to a broader and more tolerant understanding of differences among people. A knowledge of the growth of industry and especially the struggle of labor for a larger share of the fruits of production and a recognition of labor's place in industry, should assist the engineer in taking his rightful place in society and aid him in developing policies that will ensure greater good, both materially and spiritually for the greater number.

My efforts some years ago along this line of expanding the engineering curriculum met with great difficulty. Because of the many subjects that had to be given time and study, it seemed the only solution was to lengthen the course of training. Engineering is no longer an extension of a course in manual training or a study of purely technical subjects; it is a broad profession. Not so long ago, neither law nor medicine required a general training in academic or scientific subjects, but now a college course and degree is required before undertaking professional work in these fields. As in law and in medicine, the engineer deals with human beings and therefore should have a broad basis of education before undertaking his professional work. The real danger for the engineer is that the fine qualities of the field in which he is working, the exactness of the laws of nature, and the accuracy with which he must determine his design, may easily lead to narrowness of outlook and rigidity in his dealing with men. The tendency of engineers in dealing with human beings is to assume that two and two must always make four. He must be open-minded and liberal in making allowances that possibly in one case two and two may make only three and seven eighths and that in another case two and two may make four and one eighth. The engineer's problem in machine design is to secure stability of structure, efficiency, and reliability in operation. The smooth motion and decreased loss from friction that is highly desirable in machines should also be sought after in human relations.

It may seem strange, in the midst of war, when everything is being done to shorten the period of training, to get men into action, that one should advocate lengthening the course of engineering education. However, I am not speaking for today, nor is the ideal of the engineering societies for today. There is no doubt we shall eventually have victory and peace, and the engineers must be ready then for a larger role in society than ever before.

The English, in their universities, through their emphasis on the "honours" courses, have been successful in the development of the exceptional student. I remember very well a talk I had many years ago with Lord Rutherford, then Sir Ernest, the head of the Cavendish Laboratories of Cambridge University, and himself an outstanding scientist and a winner of the Nobel Prize. We were discussing engineering education in England and the United States. He said, "I grant that the average of your engineering graduates is higher than ours, but you can't touch our honour men. We don't pay much attention to the average man—he may get something from the atmosphere—but we devote ourselves to the top quarter of the class." I came back filled with the idea that if we could keep the average of our engineering graduates as high as it had been and still give more time and opportunity to the exceptional student, we would make a real contribution to engineering education and eventually to society, by engineering leadership. To that end, graduate fellowships were offered to those who graduated first and second in the "honors" course and wished to continue their studies. Only a feeble beginning has been made in this country along this line and much more could be done in establishing a broader foundation and in developing the exceptional man.

Gerard Swope, 1942 Hoover Medalist

Engineers have achieved much in the great record that America is making in war production. They will be much needed to rebuild the world not only in a material sense but humanly, which heretofore has been considered outside the engineer's field. Society has a right to look to engineers, with their training in accuracy and truth, for leadership in industry, where their services are especially needed to develop assurance of employment, to further progress in simpler design and better methods of manufacturing, the attainment of lower costs, resulting in lower prices to the community, and a wider distribution of the products of industry.

There is so much constructive work to be done to make our communities better places in which to live, to give assurance of work and leisure, without fear, in which to enjoy the benefits of better living, that the ideal of the engineering societies should constantly be before us not only for a political but also for an economic and industrial democracy.

Ultrashort Electromagnetic Waves

II—Transmission Lines at Ultrahigh Frequencies

JOHN R. RAGAZZINI
ASSOCIATE AIEE

This article is the second in a series of six on ultrashort electromagnetic waves, all presented originally before the basic science group of the AIEE New York Section as a symposium of six lectures surveying ultrahigh-frequency theory. The first article, "Electromagnetic Theory," by Doctor Ernst Weber, appeared in the March issue. This second article presents simplifications and approximations of the usual engineering solutions for the transmission line that are valid only for very high frequencies. The resulting expressions are of great practical advantage in designing transmission-line circuit elements.

PAUL C. CROMWELL, Chairman, Symposium Committee
(College of Engineering, New York University, New York, N. Y.)

THE conventional transmission line is, in the general sense, a guide for the propagation of electromagnetic energy from one point to another.[1–7] The more modern methods of dealing with a problem of this type involve a study of the field between the conducting surfaces making up the guide rather than the currents and voltages induced in these surfaces. The conventional line, however, implies the assumption that the field patterns are known and correspond to the patterns obtained under static conditions. For instance, in Figure 1, the assumed field patterns for a two-wire line and a coaxial cable are sketched.

These field patterns are based on the assumptions that they are produced by a static distribution of charge on the surfaces of the conductors and the currents flowing in these conductors. Using standard methods, the effects of the electric and magnetic field can be related to parameters commonly associated with circuits. For instance, by integrating the total flux linkages per unit length produced in the conductors per ampere of current in the conductor, the self-inductance per unit length of line can be determined. In addition, by integrating the electric field intensity from the surface of one conductor to the surface of the other, a relation between the voltage between conductors and charge per unit length can be found. The ratio of charge per volt yields the capacitance per unit length. In this way, it is possible to relate the field concepts of E and H to the circuit concepts of L and C per unit length.

The values of inductance and capacitance per unit length which result from such an integration are:

(a) For a two-wire line of circular cross section conductors:

$$L = (4)(10^{-3}) \log_e \frac{D}{a} \text{ henrys per loop meter} \quad (1)$$

$$C = \frac{1}{(36)(10^{9}) \log_e \frac{D}{a}} \text{ farads per loop meter} \quad (2)$$

where D is the separation between lines measured from center to center and a is the radius of the wire. The term loop meter implies the assumption that the inductance is calculated for both lines.

(b) For a coaxial line of circular cross section

$$L = (Q)(10^{-7}) \log_e \frac{b}{a} \text{ henrys per loop meter} \quad (3)$$

$$C = \frac{1}{(18)(10^{9}) \log_e \frac{b}{a}} \text{ farads per loop meter} \quad (4)$$

where b is the inside radius of the outer conductor and a is the outside radius of the inner conductor. The inductance formulas neglect the effects of the magnetic field inside the metal making up the conductors and the capacitance formulas neglect the proximity effects which distort the charge distributions on the surfaces of the conductors. In the case of ultrahigh-frequency propagation, however, the penetration of the magnetic field inside the conductor is quite small, and the error caused by this effect is small. Furthermore, in the case of a two-wire line, the proximity effect on the electric field is important only when the separation between wires is comparable to the diameter of the wire. In the case of coaxial cable, this latter effect is nonexistant because of the symmetrical distribution of charge.

In addition to the effects of the fields on the characteristics of the transmission line, there are the dissipative effects of the conductors and insulators which should be considered. The power losses which are produced

John R. Ragazzini is instructor of electrical engineering, Columbia University, New York, N. Y.

include the ohmic losses, which are the result of the current's passing through the conductors, and the dielectric losses produced by the oscillatory electric field in the medium used for insulation between the conductors. In ultrahigh-frequency applications, the dielectric losses are frequently neglected and the ohmic losses are assumed to be quite small. At ultrahigh frequencies the ohmic losses are produced by currents flowing only on the surfaces of the metallic conductors so that standard depth-of-penetration formulas can be used for their determination. The depth of penetration is given by the relation:

$$\delta = \frac{503.3\sqrt{\rho}}{\sqrt{f\frac{\mu}{\mu_0}}} \text{ meters} \tag{5}$$

$$\delta = \frac{0.0664}{\sqrt{f}} \text{ meters for copper} \tag{6}$$

where ρ is the resistivity in ohm-meters (1.724×10^{-8} for copper), μ/μ_0 is the relative permeability (1.0 for copper) and f is the frequency in cycles per second.

The resistance per meter of length for standard conductors of circular cross section, the radius of which is a, therefore becomes:

$$R = \frac{\rho}{2\pi a\delta} = \frac{(1.724)(10^{-8})\sqrt{f}}{(2\pi a)(0.0664)} \tag{7}$$

$$= (4.16)(10^{-8})\frac{\sqrt{f}}{a} \text{ ohms/meter} \tag{8}$$

where a is the radius of the wire in meters. The relation gives the resistance for a meter of length of a single conductor regardless of whether the current is carried on the outside of a solid copper conductor or the inside of a hollow cylindrical conductor. In the latter case, the radius of the wire refers to the inside radius of the hollow tube.

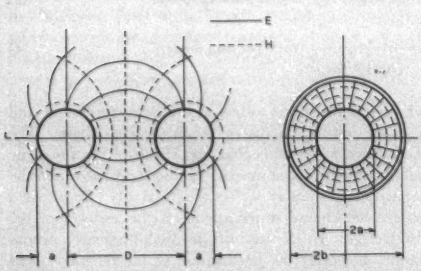


Figure 1. Field patterns for two-wire and coaxial transmission lines

In addition to these losses, there are the dielectric losses which can be minimized by the use of high-quality low-loss materials. In most cases these losses are negligible in relation to the ohmic losses. At any rate, they shall be neglected in the discussions which follow.

FUNDAMENTAL RELATIONS[1-4,11]

The relations between voltage and current on a transmission line may be determined in terms of the line parameters, L, C, R, and G, by solving the differential equations of the line. The assumption can be made that the current and voltage are sinusoidal with respect to time and may be represented by vector expressions. Considering, then, an infinitesimal section of line as shown in Figure 2, the relation for voltage at a distance of y meters from the receiving end is given by:

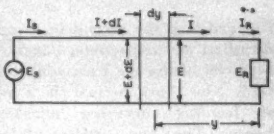


Figure 2. The long transmission line

$$\frac{dE}{dy} = I(R+j\omega L) = IZ \tag{9}$$

where R and L are the resistance and inductance of the line per loop meter respectively. Similarly, the current relation is given by:

$$\frac{dI}{dy} = E(G+j\omega C) = EY \tag{10}$$

where G and C are the effective conductance and capacitance between lines per loop meter. By differentiating equation 9 with respect to y and substituting equation 10 in the resulting expression, the following relation results:

$$\frac{d^2E}{dy^2} = Z\frac{dI}{dy} = (ZY)E \tag{11}$$

Similarly,

$$\frac{d^2I}{dy^2} = Y\frac{dE}{dy} = (ZY)I \tag{12}$$

These equations yield exponential solutions which can be combined into the conventional hyperbolic solutions in which the boundary conditions that:

$$\left.\begin{matrix} E = E_R \\ I = I_R \end{matrix}\right\} \text{ at } y=0 \qquad \left.\begin{matrix} E = E_s \\ I = I_s \end{matrix}\right\} \text{ at } y=l \tag{13}$$

where E_s and I_s are the sending-end voltage and current and E_R and I_R are the receiving-end voltage and current respectively, and l is the length of the line. The final relations are shown in equation 14.

$$E_y = E_R \cosh \gamma y + I_R Z_0 \sinh \gamma y$$
$$I_y = I_R \cosh \gamma y + \frac{E_R}{Z_0} \sinh \gamma y \qquad (14)$$

in which E_y and I_y are the voltage and current at a point y meters from the load. Also:

$$E_s = E_R \cosh \theta + I_R Z_0 \sinh \theta$$
$$I_s = I_R \cosh \theta + \frac{E_R}{Z_0} \sinh \theta \qquad (15)$$

where

$$\theta = \gamma l; \qquad \gamma = \sqrt{ZY}; \qquad Z_0 = \sqrt{\frac{Z}{Y}}$$

The constant γ is called the propagation constant of the line, θ is the line angle and is given in hyperbolic radians, and Z_0 is the characteristic impedance of the line in ohms. Generally:

$$\gamma = \alpha + j\beta \qquad (16)$$

where α is called the attenuation constant and β is the wave-length constant and is indicative of the phase shifts which are introduced by the line. An important special case of the current and voltage distributions is that in which the receiving load impedance, Z_R, is exactly equal to the characteristic impedance of the line, in which case the line is said to be matched. Making this substitution in equation 14 and simplifying,

$$E_y = E_R \epsilon^{\gamma y} = (E_R \epsilon^{\alpha y}) \epsilon^{j\beta y}$$
$$I_y = I_R \epsilon^{\gamma y} = (I_R \epsilon^{\alpha y}) \epsilon^{j\beta y} \qquad (17)$$

Thus, in a matched line, the current and voltage vary exponentially in magnitude along the line with a phase shift which is proportional to the distance traveled along the line. This special case is one of the most important in ultrahigh-frequency power transmission, and will be considered more in detail later.

Several important approximations can be made in the equations, if it is assumed that R is very small and that G is completely negligible. For instance, the characteristic impedance of the line, Z_0, can be written as follows:

$$Z_0 = \sqrt{\frac{R + j\omega L}{j\omega C}} = \sqrt{\frac{L}{C} + \frac{R}{j\omega C}} \qquad (18)$$

This expression can be expanded by means of the binomial theorem into the form (by neglecting the higher order terms):

$$Z_0 = \sqrt{\frac{L}{C}} - \frac{jR}{2\omega\sqrt{LC}} \qquad (19)$$

If the resistance of the line also is negligible, the characteristic impedance of the line is a pure resistance and can be expressed by $\sqrt{L/C}$, the value of which is given by the formula:

$$Z_0 = 276 \log_{10} \frac{D}{a} \qquad (20)$$

for a two-wire line where D is the separation between centers of the conductors and a is the outside radius of the conductors. For a coaxial line, the formula becomes:

$$Z_0 = 138 \log_{10} \frac{b}{a} \qquad (21)$$

where b is the inside radius of the outside conductor and a is the outside radius of the inside conductor. These formulas neglect the effects of the magnetic field inside the metal of the conductors and the distortions in charge distributions on the conductors caused by proximity effects. The latter effect is not present in coaxial conductors because of the symmetry of the electric field. In the case of a two-wire line, for instance, the error introduced by neglecting these effects is 5.5 per cent when the ratio D/a is 4.0, becoming progressively less as the separation between conductors becomes larger.

By applying the same approximations which led to the formulas in equations 18 and 19, the propagation constant can be expressed as follows:

$$\gamma = \sqrt{(R + j\omega L)(j\omega C)} = j\omega\sqrt{LC}\left(1 - \frac{jR}{\omega L}\right)^{1/2} \qquad (22)$$

which can be expanded by means of the binomial theorem to:

$$\gamma = \frac{R}{2}\sqrt{\frac{C}{L}} + j\omega\sqrt{LC} \qquad (23)$$

The quantity $\sqrt{LC}$ has the dimensions of the inverse of velocity. As a matter of fact, if the penetration of the magnetic field into the conductors is negligible and the dielectric permitivity of the insulation between conductors is unity, this velocity is that of light in free space. In view of this relationship and noting the fact that $\sqrt{L/C}$ is virtually the characteristic impedance if the line resistance and conductance can be neglected, the propagation constant can be expressed:

$$\gamma = \frac{R}{2Z_0} + j\frac{\omega}{v} \qquad (24)$$

where v is the velocity of propagation of the line. Since v/f is recognized as the wave length of the propagation, or more specifically as applied to the line, it is the distance over which a phase shift of 2π radians occurs, the propagation constant can be written:

$$\gamma = \frac{R}{2Z_0} + j\frac{2\pi}{\lambda} \qquad (25)$$

where λ is the wave length of the propagation and is equal to the wave length in free space if the line velocity is that of free space. It must be recognized that there are many approximations in the derivations of these constants but that they are accurate enough for use with most ultrahigh-frequency lines.

One extremely important approximation is that which can be applied to equation 14 when the resistance R

and the conductance G are completely negligible. Under these circumstances, the equations for voltage and current along the line may be written as:

$$\left.\begin{aligned} E_y &= E_R \cos \beta y + jI_R Z_0 \sin \beta y \\ I_y &= I_R \cos \beta y + j \frac{E_R}{Z_0} \sin \beta y \end{aligned}\right\} \tag{26}$$

since $\cosh j\beta y = \cos \beta y$ and $\sinh j\beta y = j \sin \beta y$. By

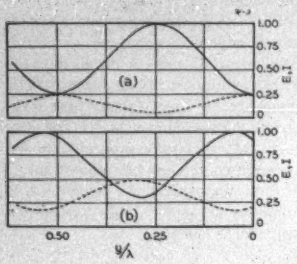


Figure 3. Voltage and current variations along line for
(*a*) $Z_R = 0.25 Z_0$
(*b*) $2Z_0 \angle 45$

means of these relations, it is possible to obtain relatively simple expressions for the current and voltage distributions along the line when a load is applied to the end of the line. If the load impedance is given by the vector quantity Z_R, then the current on the receiving end, I_R, is given by E_R/Z_R, making it possible to write the voltage equation 26 as:

$$E_y = E_R \cos \beta y + j \frac{E_R}{Z_R} Z_0 \sin \beta y \tag{27}$$

It is observed that this equation can be rearranged as follows:

$$E_y = \frac{E_R}{Z_R}\left(\frac{Z_R+Z_0}{2}\right)\left[\left(1+\frac{Z_R-Z_0}{Z_R+Z_0}\right)\cos \beta y + j\left(1-\frac{Z_R-Z_0}{Z_R+Z_0}\right)\sin \beta y\right] \tag{28}$$

The quantity $\frac{Z_R-Z_0}{Z_R+Z_0}$ is a term which appears in transmission-line equations very frequently and is called the voltage reflection factor $N\angle\phi$. This factor is not necessarily a scalar quantity but has associated with it an angle ϕ contributed by the load impedance Z_R since the characteristic impedance of the line Z_0 is a pure resistance for the case where the resistance and conductance of the line are negligible. Rewriting equation 28:

$$E_y = \frac{E_R}{Z_R}\left(\frac{Z_R+Z_0}{2}\right)[(1+N\angle\phi)\cos \beta y + j(1-N\angle\phi)\sin \beta y] \tag{29}$$

Combining terms containing the voltage reflection factor:

$$E_y = \frac{E_R}{Z_R}\left(\frac{Z_R+Z_0}{2}\right)[(\cos \beta y + j \sin \beta y) + N\angle\phi(\cos \beta y - j \sin \beta y)] \tag{30}$$

Expressing in terms of exponentials:

$$E_y = \frac{E_R}{Z_R}\left(\frac{Z_R+Z_0}{2}\right)e^{j\beta y}[1+Ne^{j(\phi-2\beta y)}] \tag{31}$$

The magnitude of the voltage along the line as a function of y, the distance from the load toward the transmitter can therefore be expressed as:

$$|E_y| = \left|\frac{E_R}{Z_R}\right|\left|\frac{Z_R+Z_0}{2}\right|\sqrt{1+N^2+2N\cos(\phi-2\beta y)} \tag{32}$$

In a similar manner, the current along the line is given by:

$$I_y = \frac{I_R}{Z_0}\left(\frac{Z_R+Z_0}{2}\right)e^{j\beta y}[1-Ne^{j(\phi-2\beta y)}] \tag{33}$$

and its magnitude:

$$|I_y| = \left|\frac{I_R}{Z_0}\right|\left|\frac{Z_R+Z_0}{2}\right|\sqrt{1+N^2-2N\cos(\phi-2\beta y)} \tag{34}$$

A plot of the current variation along a line for the case where the load impedance is twice the characteristic impedance at an angle of 45 degrees and for a load of one-fourth the characteristic impedance at a zero angle is shown in Figure 3. A special case is that in which the load impedance is exactly equal to the characteristic impedance. In that case, the reflection factor is zero, and the magnitude of the current and voltage along the line is uniform. The line is said to be "flat" under such conditions and represents a desirable mode of operation when the efficiency is to be maintained high.

TRANSMISSION OF POWER[2,3,11]

One of the primary functions of the transmission line is for the transfer of ultrahigh-frequency power from one point to another. This transmission should be accomplished with minimum losses or maximum efficiency. As an indication of how this is accomplished, the losses over a wave length (2π radians of phase shift) should be calculated. It is assumed that the line resistance, R, is low enough to permit the use of equation 34 which was derived on the basis of no losses whatsoever to represent the current magnitude along the line. If the loss is desired per unit length of line, a mean-square value of current averaged over a typical cycle of variation can be integrated and multiplied by the resistance of the line per unit length. This method will be used with the following results:

$$\text{Average copper loss} = \frac{I_y^2 R}{2} = \frac{R}{2}\left|\frac{I_R}{Z_0}\right|^2\left|\frac{Z_R+Z_0}{2}\right|^2\frac{1}{2\pi}\times \int_0^{2\pi}(1+N^2-2N\cos\psi)\,d\psi$$
$$= \frac{1}{2}\left|\frac{I_R}{Z_0}\right|^2\left|\frac{Z_R+Z_0}{2}\right|^2(1+N^2)R \text{ watts/loop meter} \tag{35}$$

This can be simplified further to:

$$\text{Average copper loss} = \frac{I_R^2(Z_R^2+Z_0^2)R}{4Z_0^2} \tag{36}$$

If the load Z_R is a resistance, the power output of the line is given by the simple expression $\frac{I_R^2 Z_R}{2}$ and the loss factor of the line can be defined as:

$$\frac{\text{Loss}}{\text{Output}} = \frac{R}{2Z_R}\left(\frac{Z_R^2 + Z_0^2}{Z_0^2}\right) \tag{37}$$

whose minimum value is reached when $Z_R = Z_0$. In other words, the maximum efficiency is reached when the line is matched, and under practical operating conditions, this condition is approached reasonably well.

When the line is matched, the current and voltage are given by equations 17, and the line attenuation for a two-wire line is therefore:

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}} = \frac{R}{2Z_0} = \frac{(1.5)(10^{-10})\sqrt{f}}{a \log_{10} D/a} \text{ nepers/meter} \tag{38}$$

where R is taken from equation 8 but the value is doubled since loop-meter values must be used to account for the outgoing and return conductors. Expressing the result in decibels, the line attenuation for a matched two-wire line is:

$$db = \frac{(1.3)(10^{-8})\sqrt{f}}{a \log_{10} D/a} \, db/\text{meter} \tag{39}$$

For the coaxial line, the attenuation under matched conditions is given by:

$$\alpha = \frac{(1.5)(10^{-10})\sqrt{f}}{\log_{10} b/a}\left[\frac{1}{a} + \frac{1}{b}\right] \text{ nepers/meter} \tag{40}$$

In terms of decibels per meter, the attenuation factor is:

$$db = \frac{(1.3)(10^{-8})\sqrt{f}}{\log_{10} b/a}\left[\frac{1}{a} + \frac{1}{b}\right] db \text{ 'meter} \tag{41}$$

For a given value of outside conductor, b, this attenuation factor is a minimum when the ratio ot b/a is approximately 3.5.

It is evident that in order to obtain the minimum attenuation given by equations 39 and 41, the line must be matched. In other words, the line must be loaded effectively by a resistance the value of which is equal to the characteristic impedance of the line. Since many loads, such as antennas, are not necessarily of the correct value, nor are they nonreactive, some means of transforming the load to the proper value must be provided. This is accomplished by the use of reactive line elements known as "stub lines" or "quarter-wave transformers," and the details of their adjustment will be given later.

REACTIVE LINE ELEMENTS

A transmission line section may be used as a reactive element by either short-circuiting or open-circuiting the receiving end of the line. The input impedance of a short-circuited line may be determined by setting E_R at zero in equations 15.

$$Z_s = \frac{E_s}{I_s} = \frac{I_R Z_0 \sinh\theta}{I_R \cosh\theta} = Z_0 \tanh(\alpha + j\beta)l \tag{42}$$

If it is assumed that the attenuation is sufficiently small so that $\sinh \alpha l = \alpha l$ and $\cosh \alpha l = 1.0$, then the input impedance can be written as:

$$Z_s = Z_0\left[\frac{\alpha l + j(1-\alpha^2 l^2)\sin\beta l \cos\beta l}{\alpha^2 l^2 + (1-\alpha^2 l^2)\cos^2\beta l}\right] \tag{43}$$

This input impedance is inductive for lengths, l, between zero and $\lambda/4$, while it is capacitive for lengths between $\lambda/4$ and $\lambda/2$. A special case of this input impedance is that in which the line length is $\lambda/4$ making $\beta l = \pi/2$:

$$Z_s = \frac{2Z_0^2}{Rl} = \frac{8Z_0^2}{R\lambda_0} \tag{44}$$

where R is the resistance per loop meter, l is the length of the line in meters, and Z_0 is the characteristic impedance. The input impedance reaches a maximum value at this length and the input impedance is virtually nonreactive. It is not exactly so because of the slight phase angle contained in the characteristic impedance Z_0.

A measure of the effectiveness of a short-circuited line section as a reactive element is the Q of the element defined as:*

$$Q = \frac{X_L}{R} \tag{45}$$

for lengths considerably less than $\lambda/4$. Then using 43 by taking the ratio between the reactive component and the resistive component,

$$Q = \frac{(1-\alpha^2 l^2)\sin\beta l \cos\beta l}{\alpha l} \tag{46}$$

A useful approximation which can be applied in estimating the lengths of short-circuited line sections is that in which the attenuation factor is negligible. Then:

$$Z_s = jZ_0 \tan\beta l \tag{47}$$

Similar relationships can be derived for an open line section using equations 26 this time setting I_R at zero. The relations are:

$$Z_s = \frac{E_s}{I_s} = Z_0 \coth(\alpha + j\beta)l \tag{48}$$

$$Z_s = Z_0\left[\frac{\alpha l - j(1-\alpha^2 l^2)\sin\beta l \cos\beta l}{\alpha^2 l^2 + (1-\alpha^2 l^2)\sin^2\beta l}\right] \tag{49}$$

$$Q = \frac{(1-\alpha^2 l^2)\sin\beta l \cos\beta l}{\alpha l} \tag{50}$$

and if the attenuation is negligible,

$$Z_s = -jZ_0 \cot\beta l \tag{51}$$

The input impedance of an open-circuited line is capacitive if the length of the line section is less than $\lambda/4$ and inductive if the line length is between $\lambda/4$ and $\lambda/2$. If the length is just $\lambda/4$, the impedance becomes

* This definition is limited in scope and is applicable only to lines considerably shorter than one-quarter wave length. The basic definition for the Q of a circuit is the ratio of the maximum energy storage in the system divided by the loss per cycle. In the case of short lines, however, the energy storage is mostly magnetic and the definition given in equation 45 is approximately correct.

nonreactive and reaches a minimum value given by:

$$Z_s = \frac{Rl}{2} \tag{52}$$

The transmission line can, therefore, be used to obtain inductive or capacitive components at ultrahigh frequencies with values of Q not otherwise realizable. These short line sections are known as "stub lines" and can be used as filter elements, and as reactances for use in line matching to be described later.

RESONANT CIRCUIT ELEMENTS[9-11,16]

Transmission-line sections find a very important use in applications where high-Q resonant circuit elements at high frequencies are required. For instance, a short-circuited line element has the characteristics of a resonant circuit when line lengths reach $\lambda/4$ or odd multiples thereof. A plot of the reactance variations of a short-circuited dissipationless transmission line as

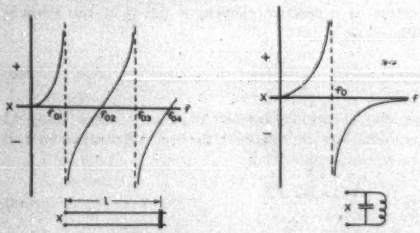


Figure 4. Input reactance of short-circuited line and tuned circuit

given by equation 47 is given in Figure 4. In the same figure are given the reactance variations of a parallel tuned circuit. It is observed that at certain frequencies f_{01}, f_{02}, and so forth, the impedance rises to infinity while the circuit becomes inductive at the frequencies slightly below these values and capacitive at the frequencies above these frequencies. These variations are exactly similar to those of a parallel tuned circuit, thus making it possible for a short-circuited line to replace it in these frequencies. The infinite impedances are reached for line lengths such that:

$$\beta l = \frac{(2n+1)\pi}{2} \tag{53}$$

or

$$l = \frac{(2n+1)\lambda}{4} \tag{54}$$

where n is an integer. Similarly, for line lengths which are multiples of $\lambda/2$, the input impedance of a short-circuited line varies in the same way as a series resonant circuit.

A practical line has losses however, which make the input impedance finite at resonance as given by equation 44. The lower the line losses, the higher is the input impedance which can be developed across the input terminals of the line. An important factor which should be investigated is the variation of the magnitude of the input impedance as the frequency is varied slightly so that an estimate of the Q of the tuned circuit can be made. Using equation 42 this variation may be evaluated,

$$Z_s = Z_0 \frac{\sinh(\alpha l + j\beta l)}{\cosh(\alpha l + j\beta l)} \tag{55}$$

At resonance, the angle βl is $\pi/2$, but for slight frequency deviations of $\Delta\omega$, the angle βl becomes $\left(\pi/2 \pm \frac{\Delta\omega}{v} l\right)$ where v is the velocity of propagation on the line and l is the length of the line. Thus the input impedance, Z_s, for values near resonance can be expressed by:

$$Z_s = Z_0 \frac{\sinh\left[(\alpha l + j\pi/2) + j\frac{\Delta\omega}{v} l\right]}{\cosh\left[(\alpha l + j\pi/2) + j\frac{\Delta\omega}{v} l\right]} \tag{56}$$

Expanding and simplifying, the following form may be obtained:

$$Z_s = \frac{Z_0}{\tanh\left(\alpha l + j\frac{\Delta\omega}{v} l\right)} \tag{57}$$

If the magnitude of both the attenuation factor, α, and the frequency deviation, $\Delta\omega$, is small, then the $\tanh\left(\alpha l + j\frac{\Delta\omega}{v} l\right)$ is virtually the same as $\left(\alpha l + j\frac{\Delta\omega}{v} l\right)$. Hence:

$$Z_s = \frac{Z_0/\alpha l}{1 + j\frac{\Delta\omega}{\alpha v}} \tag{58}$$

The Q of the resonant circuit can be defined as the ratio of the resonant frequency and twice the frequency variation required to reduce the impedance to 0.707 times the resonant value. This condition is reached when:

$$\frac{\Delta\omega}{\alpha v} = 1 \tag{59}$$

Hence,

$$Q = \frac{\omega_0}{2\Delta\omega} = \frac{\pi f_0}{\alpha v} = \frac{2\pi Z_0}{R\lambda_0} \tag{60}$$

where R is the resistance per loop meter of line, Z_0 the characteristic impedance of the line and λ_0 is the wave length of the propagation measured at line velocity.

An open line has characteristics similar to those of the short-circuited line, except for an interchange of the series and parallel resonant points. The input impedance of an open line is given by equation 48.

$$Z_s = Z_0 \coth (\alpha l + j\beta l) \tag{61}$$

Near the first resonant point, when $\beta l = \pi/2$, the input impedance is

$$Z_s = Z_0 \alpha l \left(1 + j \frac{\Delta\omega}{\alpha v}\right) \tag{62}$$

The Q of a resonant open line is given by exactly the same formula as that for the short-circuited line, equation 60.

The resonant line can be used as a tank circuit for oscillators, amplifiers, or measuring devices with values of Q and input impedance not realizable by other methods. Since the frequency stability of oscillators depends to a large extent on the Q of the resonant circuits, line sections are particularly adapted to ultrahigh-frequency applications.

THE LINE AS A MEASURING DEVICE

One of the uses of the transmission line is in the measurement of various quantities such as frequency and impedance at ultrahigh frequencies. One of the most familiar of these applications is the use of lecher wires for the measurement of frequency. For instance, if a short-circuited transmission line is coupled to a source of ultrahigh-frequency power the frequency of which is to be measured, the line becomes resonant when its effective length is an integral number of half wave lengths. At the resonant condition, the currents in the line become large and the power absorption from the oscillator increased. If the short circuit is moved down the line, a distance equal to a half wave length, as shown in Figure 5, the circuit becomes resonant again and an indication is noted. This indication is either a grid current dip in the oscillator tube or a measure of the current in the line itself by some means such as a crystal microammeter or a low-range thermal instrument. The frequency of the oscillator is given by:

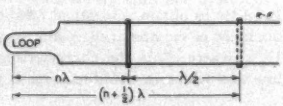


Figure 5. Lecher-wire system

$$f = \frac{v}{\lambda} \tag{63}$$

where $v = 1/\sqrt{LC}$, virtually the velocity of light and λ is twice the movement of the short-circuiting stub for consecutive indications. Various refinements have been suggested and used in this measurement, but, fundamentally, they are all based on the principle outlined. It is noted that the measurement of frequency has been converted into a measurement of length.

Another important measurement which can be made with a transmission line is that of impedance at ultrahigh frequencies. Here too, the value of impedance is determined by converting all measurements into those of length, and relative voltage or current. The unknown impedance is placed at the end of a transmission line as shown in Figure 6. The variation of voltage and current along the line is given by equations 32 and 34. The voltage E or the current I need be measured only in relative terms by means of a coupling loop and thermal milliammeter which measures current in the line or a special quarter-wave voltmeter which is a thermal milliammeter connected to the end of a quarter-wave length line. The data will yield the relative voltages I_{max} and I_{min} or E_{max} and E_{min} from which can be calculated the magnitude of the reflection factor. Furthermore, the location of either the voltage maximum or the current minimum is used to calculate the phase angle of the load impedance.

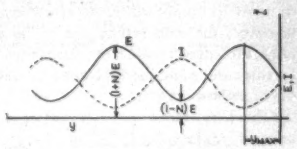


Figure 6. Voltage and current distribution on unmatched line

The reflection factor, N, is determined by noting that the maximum and minimum values of voltage along the line are given by equation 32

$$\frac{E_{max}}{E_{min}} = \frac{I_{max}}{I_{min}} = \frac{1+N}{1-N} \tag{64}$$

from which

$$N = \frac{E_{max}/E_{min} - 1}{E_{max}/E_{min} + 1} \tag{65}$$

The same result is obtained by replacing the voltage maximum and minimum with the current maximum and minimum in equation 65. The phase angle of the reflection factor, ϕ, is obtained by consideration of equation 32 or 34 in which the value of the cosine term becomes unity. For this condition:

$$\phi = 2\beta y_{max} = \frac{4\pi}{\lambda} y_{max} \tag{66}$$

where y_{max} is the distance of the voltage maximum or current minimum as measured from the load end. The magnitude and phase angle of the unknown impedance, Z_s, can be found by solving the following equation vectorially:

$$N \angle \phi = \frac{Z_s - Z_0}{Z_s + Z_0} \tag{67}$$

Charts have been devised which make the solution of this problem graphical rather than analytical, but the basic theory is identical.

In this manner, the measurement of impedance at ultrahigh frequencies is possible by the measurement of

distance and relative current or voltage. The characteristic impedance, Z_0, which appears in equation 67 is calculated from equation 20 or 21. The impedance which is being measured need not be a dead load such as a resistor, but may be a dynamic load such as an antenna in which the radiation resistance is included in the measurement.

LINE MATCHING AND STUBBING[3,4]

It has been shown that it is desirable to terminate transmission lines with their characteristic impedance in order to obtain optimum efficiency. In many cases, however, the load which has to be supplied does not have the correct value of impedance to match a line. In this case, some method must be devised to transform the impedance of the load to the proper value. One simple impedance transformer is a quarter-wave-length line section interposed between the line and the load as shown in Figure 7. If the dimensions of the quarter-wave transformer are properly chosen, it is possible to transform the impedance of the load to match the line. In order to do this, it is necessary to know the impedance of the load at the operating frequency, and this must be measured by the method outlined in the preceding section. The characteristic impedance of the line which is to be matched Z_0 must be calculated also. With this information, reference is made to equation 26, and the ratio of input voltage and current taken for the condition that the angle βy is $\pi/2$ radians. This yields the input impedance of the quarter-wave-length line terminated by a load impedance of Z_R:

Figure 7. Quarter-wave transformer for nonreactive load

$$Z_s = \frac{I_R(Z_0')^2}{E_R} = \frac{(Z_0')^2}{Z_R} \tag{68}$$

The input impedance given by equation 68 should be made equal to the characteristic impedance of the line, Z_0. To satisfy this condition, the characteristic impedance of the inserted quarter-wave transformer is obtained by solving equation 68:

$$Z_0' = \sqrt{Z_R Z_0} \tag{69}$$

The matching section should be proportioned to have a characteristic impedance which is the geometric mean between the load impedance and the line impedance.

Another method which is used to transform the impedance of a load to match that of the line is by the use of matching stub lines. In Figure 3 are given plots of voltage and current along the line for two conditions of load. At any point, the ratio of the voltage to the current is the apparent impedance of the line at that point or conversely, the ratio of current to voltage is the admittance of the line at that point. The admittance varies in value over a considerable range as the point under observation is moved along the line. These variations are shown in Figure 8 in which the conductance and susceptance of the line are plotted separately. At some points, the conductance of the line is $1/Z_0$. This point would give the correct value of impedance to match the line were it not for the fact that there is associated with this conductance a considerable amount of susceptance. The latter can be cancelled out, however, by placing at this point a reactive line element or stub line whose susceptance is equal and opposite to that presented by the line. Thus, so far as the portion of the line ahead of the load is concerned, the apparent impedance of the line in parallel with the stub line is equal to the characteristic impedance. As indicated in Figure 8, the major portion of the line is matched providing the stub is placed close to the load.

To determine the proper location of this stub line, the admittance of the line at any point, y, is calculated by taking the ratio of equations 31 and 33:

$$Y(y) = \frac{1}{Z_0}\left[\frac{1 - Ne^{j(\phi - 2\beta y)}}{1 + Ne^{j(\phi - 2\beta y)}}\right] \tag{70}$$

This expression can be simplified into real and imaginary components which represent the conductance and susceptance of the line. After simplification, the real component of the admittance is:

$$G(y) = \mathrm{Re}\,Y(y) = \frac{1}{Z_0}\,\frac{1 - N^2}{1 + N^2 + 2N\cos(\phi - 2\beta y)} \tag{71}$$

In order to obtain a matched condition, the input conductance of the line at the point, y, should have a value $1/Z_0$, where Z_0 is the characteristic impedance of the line and which in this discussion is assumed to be non-

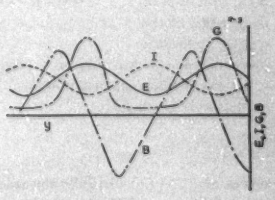


Figure 8. Admittance variations on unmatched line

reactive. For a matched condition, then

$$G(y) = \frac{1}{Z_0} \tag{72}$$

which is true when

$$\cos[\phi - 2\beta y + (2n+1)\pi] = -N \tag{73}$$

where n is an integer. Now, from equation 66, the angle of the reflection factor is given by:

$$\phi = 2\beta y_{max} \tag{74}$$

Substituting this relation in equation 73 and simplifying,

$$\frac{y - y_{max}}{\lambda} = \frac{\pm \cos^{-1} N}{4\pi} + \frac{2n+1}{4} \tag{75}$$

where y_{max} is the distance of the voltage maximum measured from the load, and $(y - y_{max})$ represents the distance measured from the voltage maximum back toward the transmitter. If the reflection factor is expressed in terms of the voltage ratio E_{max}/E_{min}, and referring to $(y - y_{max})$, as Δy the location of the stub line is given by:

$$\frac{\Delta y}{\lambda} = \frac{2n+1}{4} \pm \frac{1}{4\pi} \cos^{-1}\left[\frac{E_{max}/E_{min} - 1}{E_{max}/E_{min} + 1}\right] \tag{76}$$

The length and type of stub line required at these points is given by the imaginary part of the line admittance as expressed by equation 70. By simplifying the resulting expressions, this input admittance becomes:

$$B(y) = \frac{1}{Z_0} \frac{-2N \sin(\phi - 2\beta y)}{1 + N^2 + 2N \cos(\phi - 2\beta y)} \tag{77}$$

At the points where proper matching of the conductance occurs, the $\cos(\phi - 2\beta y) = -N$, thus making possible the simplification of equation 77 to:

$$B(y) = \frac{1}{Z_0}\left(\frac{\mp 2N}{\sqrt{1 - N^2}}\right) \tag{78}$$

where the signs correspond to those of equation 76. To counterbalance this susceptance, the stub line must present a susceptance which is equal and opposite to the value given by equation 78. Hence,

$$B_{stub} = \frac{\pm 2N}{Z_0\sqrt{1 - N^2}} \tag{79}$$

where again the signs correspond to those of equation 76. If the reflection factor is expressed in terms of voltage ratio and inverting, then

$$X_{stub} = \frac{-1}{B_{stub}} = \mp Z_0 \frac{\sqrt{E_{max}/E_{min}}}{E_{max}/E_{min} - 1} \tag{80}$$

While it is possible to calculate the length of the stub line by using equations 47 or 51, it is far simpler to express the results by means of graphical representations. These graphs which are extremely useful in locating and adjusting stubs are given in Figure 9.

Thus, in order to match a line by means of stub lines, it is necessary to measure the relative voltage or current along the line before the stub line is installed. Also necessary is the location of the voltage maximum or the current minimum. From these data, using the curves, it will be possible to match the line within reasonable limits. Generally speaking, it is found that a perfect match is extremely difficult to obtain, but voltage ratios of about 1.2 can be obtained at the first setting. Improvement of the voltage ratio can be obtained experimentally by slight adjustment of the stub-line length and position.

CONCLUSIONS

Although an exhaustive survey of long transmission lines at ultrahigh frequencies has not been attempted, various important concepts have been developed. The ultrahigh-frequency transmission line can be treated in general as a nondissipative system in which the effects of losses can be approximated later. In the line stubbing and matching relations and line measurement problems, the dissipation of the line has been neglected and, as practical applications have proved, this approximation is justifiable. The use of the line as a circuit element, both reactive and resonant, has been given considerable weight, since this use is unique at ultra high frequencies. Further details and other applications will be found in the brief bibliography which has been appended.

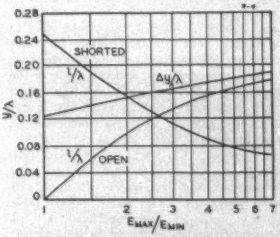


Figure 9. Chart for computing matching stub lengths and locations

Δy is the distance of the stub from the voltage maximum measured toward the source for the short-circuited stub and toward the load for the open stub. l is the length of the stub and λ is the wave length of the wave on the line

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9. Charts for Transmission Line Measurements, **P. S. Carter.** *RCA Review*, volume 3, January 1939, pages 355–68.

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11. Symposium on Ultrahigh Frequency—Radiating Systems and Wave Propagation, **A. G. Kandoian.** *Electronics*, April 1942, pages 39–68.

INSTITUTE ACTIVITIES

South West District Technical Meeting to Be Held at Kansas City, Mo., April 28–30

As announced in previous issues, a technical meeting of the AIEE South West District will be held at Kansas City, Mo., April 28–30, 1943. At the same time the annual engineering meeting of the Missouri Valley Electric Association also will be held in that city. Because of the war it was deemed desirable to hold these meetings concurrently in order to conserve time and transportation for those interested in attending both. Headquarters for both meetings will be in the Hotel Continental.

Both organizations, desiring to be of the greatest possible service to the war effort, have assembled papers for presentation and discussion relating so far as practicable to the problems of the electrical industry during wartime. Each organization will have a separate program except for two joint sessions, as indicated, which will appear in both programs. The AIEE South West District includes nine Sections and 14 Student Branches in the states of Missouri, Arkansas, Kansas, Oklahoma, Texas, and New Mexico. The MVEA operates in the states of Iowa, Nebraska, Missouri, Kansas, and Oklahoma.

JOINT SESSIONS

Especial attention is called to the two joint sessions of AIEE and MVEA for members and guests. The opening session on Wednesday morning will be devoted to a broad outline of the problems before these organizations and their members at the present time. The second joint session on Thursday afternoon will be devoted to the presentation and discussion of one of the most important matters before the country today, namely, the conservation of critical materials which are so badly needed in the war effort. Opportunity will be afforded for discussion to bring out helpful ideas relating to these subjects.

SPECIAL FEATURES FOR STUDENTS

Several of the nearby engineering schools have signified their intention of substituting attendance at the technical meeting and Student Branch conference for their usual inspection tours which now are impossible because of wartime restrictions. The features arranged especially for students are:

1. A student session arranged by Professor W. F. Gray, chairman, District committee on student activities, will be held on Wednesday afternoon. The program will be in charge of the students and several student papers will be presented.

2. Arrangements have been made for student consultations with industry representatives. The purpose is to give students an opportunity to ask questions and to familiarize themselves with the requirements and opportunities in some of the fields of electrical engineering. The industries and representatives are listed in the program.

3. Each student who registers will be taken to the Thursday noon luncheon by a member of the AIEE. This will afford a splendid opportunity for the students to become acquainted with the older members of the electrical industry and to learn of AIEE affairs from the several talks to be given by officers of the Institute.

4. Certain inspection trips have been arranged particularly for students who will attend the meeting. They are as follows:

Kansas City Power and Light Company Lighting Institute
Kansas City Power and Light load dispatching room and operating building
Kansas City, Kans., generating plant
Kansas City, Kans., water works

Other trips also may be arranged by the time of the meeting.

The personnel of the inspection trips committee is: A. E. Bettis, *chairman*; J. A. Dailey; H. A. Howery; A. L. Mullergren; W. J. Squire.

South West District Technical Meeting

Wednesday, April 28

8:00 a.m. Registration

9:30 a.m. General Session (AIEE-MVEA)

Address of welcome: "Kansas City in Wartimes." **L. P. Cookingham**, city manager, Kansas City, Mo.

Address: "What the AIEE Is Doing to Aid the War Effort." **E. T. Mahood**, vice-president, South West District, AIEE

Address: "What the MVEA Is Doing to Aid the War Effort." **Arthur L. Mullergren**, president, Missouri Valley Electric Association

Address: "The Engineer and the War." **Harold S. Osborne**, president, AIEE

Address: "Electrical Indicating Instruments in Wartimes." **Harold L. Olesen**, assistant sales manager, Weston Electrical Instrument Corporation

2:00 p.m. Student Session

A Comparative Study of the Rationalized and Unrationalized M.K.S. Unit System. **G. L. Johnson** and **V. J. McKale**, University of Kansas

Routine Testing of Residential Watt-Hour Meters. **J. G. McDonald**, Kansas State College

The Operation of Single-Phase Wattrhour Meters. **Franklin Fansher**, University of Missouri

Revisions of the Electrical Code Due to the War Effort. **L. V. Randle**, Southern Methodist University

2:00 p.m. Electrical Machinery

DP.* Chlostatic Generator Leads. **C. R. Bennett**, The Okonite Company

DP.* Conservation of Critical Materials in Transformer Design and Application. **J. K. Hodnette**, Westinghouse Electric and Manufacturing Company

DP.* Effect of Control on the Characteristics of D-C Series and Shunt Motors. **A. A. Merrill**, General Electric Company

DP.* Normal and Emergency Loading of Power Transformers. **H. B. Keath** and **W. Godin**, Wagner Electric Corporation

DP.* Graphic Solutions in Unbalanced Transformer Loading. **C. M. Lovell**, Moloney Electric Company

6:30 p.m. Dinner Arranged by MVEA

Thursday, April 29

7:30 a.m. Breakfast Meeting of Student Branch Counselors

7:30 a.m. Breakfast Meeting of Student Branch Officers

9:00 a.m. Clinic on Section Operations and Management

9:30 a.m. Student Consultations With Industry Representatives

R. L. Baldwin has arranged for a group of men to be available with whom students who wish can confer. These men are listed in the adjoining column.

- **PAMPHLET** reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.
- **ABSTRACTS** of most papers appear elsewhere in this issue.
- **PRICES** and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at

Industry	Representative
Aviation	**Howard K. Morgan**, T.W.A.
Communication	**C. H. Weiser**, Southwestern Bell Telephone Company
Consulting Engineering	**R. L. Baldwin**, Burns and MacDonnell Engineering Company
Electrical Manufacturing	**George Fiske**, General Electric Company
Power and Light Operating	**G. O. Brown**, Kansas City Power and Light Company
Radiobroadcasting	**Arthur B. Church**, Midland Broadcasting Company
Transportation	**J. A. Parkinson**, Atchison, Topeka, and Santa Fe Railroad Company

SECTION OPERATION AND MANAGEMENT

Delegates from the various Sections in the District are expected to attend the clinic that will be conducted by C. W. Mier of Dallas, Tex., starting at 9:00 a.m. on Thursday. Mr. Mier recently was nominated for Director of the Institute. In addition to the delegates, it is hoped that past officers and active members of Sections will attend in order to participate in the discussion. Certain questions relating to Section operation and management will be presented for discussion. Charts and displays of material will be used. This offers an opportunity for Sections to bring up questions, the discussion of which might be helpful to other Sections. It is expected that views will be crystallized on as many of these questions as practicable so that the conclusions of the conference may be presented to the District executive committee, which will meet immediately afterward.

DISTRICT EXECUTIVE COMMITTEE MEETING

The District executive committee meeting will be held at 10:30 a.m. on Thursday and in addition to considering the report from the clinic on Section operation and management, will discuss matters relating to AIEE activities throughout the District. District Secretary R. G. Kloeffler is arranging an agenda.

LUNCHEON AND DINNERS

AIEE members and guests are invited to the MVEA dinner Wednesday evening and may purchase tickets at the registration desk.

There will be a luncheon Thursday noon for AIEE members and guests. A. E. Bettis, vice-president of the Kansas City Power and Light Company, will preside and brief talks will be made on Institute matters by the national officers, as indicated on the program. A feature of this luncheon will be student attendance. Each senior member will bring a student as his guest, thus offering the students an opportunity to get acquainted with the older members.

A dinner for Thursday evening is being arranged by an AIEE committee. It will be for men only and the dinner will be followed by a talk. MVEA members are invited and may purchase tickets at the registration desk.

REGISTRATION

Members who receive an advance registration card by mail should fill in and return the card promptly. This will save time on arrival at the meeting, as badges for advance registrants will be prepared in advance. No registration fee will be charged for members, enrolled students, and the immediate families of members. There will be a $2.00 registration fee for all other nonmembers.

HOTEL RESERVATIONS

The hotels and registration committee, C. G. Roush, chairman, 101 West 11th Street, Kansas City, Mo., is doing everything possible to provide hotel accommodations for those who will attend. It is believed that adequate accommodations will be available. Members and guests should write directly to the hotel of their choice as early as possible for accommodations.

In Table I are given the rates for the Hotel Continental, meeting headquarters, and several other hotels within a convenient distance.

Table I. Hotel Rates

	Prevailing Rates (With Bath)		
	Single	Double	Twin Beds
Continental Headquarters Hotel	$2.50–$4.00	$3.50–$5.00	$4.00–$7.00
Muehlebach	3.25– 7.00	4.50– 8.00	5.50– 9.00
Pickwick	2.50– 4.00	3.50– 6.00	4.50– 6.00
Phillips	2.50– 5.00	4.00– 8.00	5.00– 8.00
President	2.75– 5.00	4.00– 6.50	5.00– 7.00

Tentative Technical Program and Features

the meeting cannot be assured. Only numbered papers are available in pamphlet form.

● COUPON books in $5 denomination are available for those who may wish this convenient form of remittance.

● PAPERS regularly approved by the technical program committee ultimately will be published in "Transactions"; many will appear in "Electrical Engineering."

Each of these men will be in a separate room from 9:30 a.m. on the morning of April 29 to talk with any student or group of students who care to come and talk with him about the conditions, prospects, and future in his particular industry. The talks will be entirely informal and students are welcome to come and go as they please. These men will all do their best to give the student any information desired.

9:00 a.m. Communications

DP.* Dallas-San Antonio Intercity Toll Cable to Provide Communication Facilities to Meet War Needs in Texas. **G. A. Dyer,** Southwestern Bell Telephone Company

DP.* Teaching Ultrahigh-Frequency Techniques. **E. W. Hamlin,** University of Texas

DP.* Communications for Civilian Defense. **O. S. McDaniel,** Southwestern Bell Telephone Company

43-72. Train Communication. **L. O. Grondahl** and **P. N. Bossart,** Union Switch and Signal Company (Presentation by title)

10:30 a.m. District Executive Committee Meeting

12:00 m. AIEE Luncheon

After the luncheon the following national officers will make informal talks on AIEE and civic affairs: **P. L. Alger,** chairman, technical program committee; **H. H. Henline,** national secretary; **F. J. Meyer,** director.

2:00 p.m. Symposium on Critical Materials and Equipment (AIEE-MVEA)

Address: "The Organization and Function of the Conservation Division of the War Production Board." **H. M. MacDougal,** War Production Board

Address: "Conservation of Critical Materials." **H. S. Osborne,** president, AIEE

Address: "Conservation of Critical Materials in the Telephone Industry." **C. W. Nystrom,** Southwestern Bell Telephone Company

Address: "AIEE Guides for the Selection and Operation of Electrical Equipment." **J. R. North,** chairman, standards committee, AIEE

Address: "Emergency Measures to Increase Output of Generating Equipment." **A. C. Monteith,** chairman, committee on power generation, AIEE

6:30 p.m. Dinner for men only, and address

Arranged by AIEE

Friday, April 30

9:00 a.m. Selected Topics

DP.* Wartime Trends in Arc Welding. **G. C. Quinn,** Allis-Chalmers Manufacturing Company

DP.* Safety Engineering Instruction in Oklahoma Agricultural and Mechanical College. **A. Nestor,** Oklahoma A. & M. College

43-74. Industrial Control: Dynamic Braking of a D-C Shunt Motor and Load. **G. F. Leland** and **L. T. Rader,** General Electric Company

DP.* Standards and Fundamentals of Amplidyne Practice. **F. E. Craver,** General Electric Company

DP.* Inductive Heating in Substitute Ferrous Sections Used in Switchgear. **S. C. Killian,** Delta Star Electric Company

9:00 a.m. Transportation

43-75. Advantages of High-Speed Traction Motors. **C. A. Atwell,** Westinghouse Electric and Manufacturing Company

DP.* Wartime Operating Experiences and Practices in Kansas City. **L. L. Davis,** Kansas City Public Service Company

DP.* Maximum Utilization of Transit Equipment. **G. M. Woods,** Westinghouse Electric and Manufacturing Company

DP.* Operating Experiences with Trolley Coaches in St. Joseph. **F. Norman Hill,** St. Joseph Railway, Light, Heat, and Power Company

*DP: District paper; no advance copies are available; not intended for publication in *Transactions*.

Skyline of Kansas City, Mo., where the South West District technical meeting, April 28–30, 1943, will be held

If satisfactory arrangements cannot be made directly with the hotels, members may write to Mr. Roush. Certain hotels conveniently located with rates appropriate for students have been selected. It is suggested that student counselors be consulted by students who expect to attend and that the counselors in turn communicate with Mr. Roush in case they need any assistance in finding suitable accommodations.

GENERAL INFORMATION

In keeping with the spirit of this meeting, no special entertainment will be provided.

An information desk will be maintained in the lobby to assist out-of-town members in arranging for tickets to shows and dances, of which Kansas City affords a wide and interesting variety. It is expected that members will make up their own parties.

COMMITTEES

District Meeting:

E. T. Mahood, vice-president South West District; R. G. Kloeffler, secretary, South West District; A. T. Campbell, P. C. Ellis, W. F. Gray, I. T. Monseth, R. Randall, G. G. Roush, P. H. Underwood, C. V. Waddington.

Meetings and Papers:

V. P. Hessler, *chairman;* M. E. Bretschneider, A. T. Campbell, R. W. Gaskins, L. R. Hammond, H. P. Heafer, E. A. Heath, J. Lewis Jones, R. M. Kerchner, H. H. Robison, W. E. Stemmer.

Student Activities:

R. L. Baldwin, *chairman;* D. D. Clarke, W. F. Gray, R. G. Kloeffler, R. J. W. Koopman, M. P. Weinbach.

Publicity and Attendance:

A. T. Campbell, *chairman;* C. C. Cornelius, L. H. Schultz.

Finance:

George Fiske, *chairman.*

Hotels and Registration:

C. G. Roush, *chairman;* A. F. Hartung, S. H. Pollock.

Luncheon and Dinner:

P. C. Ellis, *chairman;* L. L. Davis, S. M. DeCamp, R. L. Frisby, J. E. Lauoder, C. M. Lytle.

Future AIEE Meetings

District Technical Meeting
Pittsfield, Mass., April 8–9, 1943

District Technical Meeting
Kansas City, Mo., April 28–30, 1943

National Technical Meeting
Cleveland, Ohio, June 21–25, 1943

National Technical Meeting
Salt Lake City, Utah, September 2–4, 1943

H. A. Johnston Named AIEE Advertising Manager

H. A. Johnston has been appointed AIEE advertising manager, succeeding the late C. A. Graef (*EE, Feb. '43, p. 73*). He has had a well-rounded experience in technical and industrial advertising, and recently resigned the position of advertising manager of the Triplex Machine Tool Corporation, New York, N. Y., to assume his new duties.

Mr. Johnston has a knowledge of marketing, merchandising, and research as well as an understanding of technical and engineering magazine publishing and advertising. For a number of years he was vice-president of the Sachs Industrial and Technical Advertising Company, a former New York advertising agency. He has served also as advertising manager of *Fire and Water Engineering* and as eastern advertising manager of *Municipal Engineering Magazine.*

He was born in Brooklyn, N. Y., and has been identified with the advertising profession during his entire business career. He attended Mount Hermon School and Rutgers University. Upon leaving college, he was associated with the advertising department of the SKF Ball Bearing Company and the New York Non-Fluid Oil Corporation.

Standard Pronunciation of "Ignitron" Urged

The newly organized AIEE committee on electronics, as its first official act in the field of standardization, has asked Thomas Spooner (F '29) to comment on the pronunciation of the word "ignitron." There have arisen two different pronunciations of the word, which leads to confusion. Mr. Spooner is chairman of the subcommittee on electronics of the standards co-ordinating committee 7 of the AIEE standards commiteee. His comments follow.

There are thousands of young engineers and others who will meet the term "ignitron" for the first time each year, and anything that can be done to assist them in remembering the device and the nature of its operation is well worth while. When the word first was coined and agreed to by the inventor and the original manufacturer, it was written "ignitron," to indicate that the "i" should be pronounced as "eye" and that the accent should fall on the second syllable. The purpose was to convey the idea of igniting the arc by means of an ignitor. The pronunciation with the short "i" and the accent on the first syllable does not convey readily the impression of ignition. (I hope no one will suggest that ignition applies only to combustion, because the term "ignitron" is here to stay.) This second pronunciation undoubtedly came about from the too slavish following of rules of psonunciation. In this instance the rules should be ignored.

It is inadvisable to have two pronunciations, since it may be thought by the uninitiated that two different devices are being discussed when both pronunciations are used, which frequently happens at discussions during AIEE meetings. Moreover, it may appear to the layman that the follower of one or the other pronunciation does not know what he is talking about if he cannot even pronounce correctly the name of the apparatus which he is discus-

sing. To eliminate confusion and assist the novice in remembering the device, let us standardize on "ignitron."

There is also a spelling difficulty which frequently arises. The ignition device in the ignitron is spelled ignitor (not igniter).

SECTION • • • • •

Aircraft Group Being Formed by Los Angeles Section

The AIEE Los Angeles Section is engaged in the formation of an aircraft group to provide a medium for the interchange of ideas and the discussion of problems pertaining to electricity in aircraft. This is the first group in this field to be established by an Institute Section. Interest in the aircraft phase of electrical engineering as a result of the widespread aircraft industry in the area of the Los Angeles Section has given impetus to the establishment of the new group, first specialized technical division to be set up by this Section. It is reported that the San Diego Section is forming a similar group.

The Los Angeles Section recently modified its bylaws to facilitate the formation of specialized groups. Plans include provision for the election of additional officers known as divisional vice-chairmen of the Los Angeles Section, to be elected as needed. Each divisional vice-chairman will form a divisional committee, which will arrange, through the regular machinery of the Section, for as many programs as required in the specialized field.

The formation of groups interested in special phases of electrical engineering within AIEE Sections is not new. A number of Sections already have technical groups on power, transportation, illumination, and communication. In 1934 a plan was proposed to increase member participation in specialized technical group work within the Sections. An outline of this plan appears in an item entitled "Technical Committee Activities Proposed for Sections and Districts," (*EE, Apr. '34, p. 631*). After the plan was discussed by various committees and at various conventions (*EE, Aug. '34, p. 1232; Aug. '35, p. 900; Aug. '36, pp. 930–2*), the proposal was incorporated in the following resolution, adopted by the board of directors on May 25, 1936:

RESOLVED: That the Sections be encouraged by all officers of the Institute and by the technical program committee and the national technical committees in particular to take a greater part in the technical activities of the Institute through such proper channels as they may select, examples being the formation of Section technical committees, the holding of specialized technical group meetings, the sponsoring of specific technical courses, and similar arrangements which have been used successfully or may be worked out in the future.

In an effort to stimulate further interest in establishing the aircraft group, the Los Angeles Section meeting held February 9, 1943, was devoted to electricity in aircraft. The program featured talks by Gilbert F. Burnett, staff electrical engineer of the Lockheed Aircraft Corporation, who spoke on "Development of Electrical Apparatus in Aircraft"; Charles McCabe, electrical engineer for the Consolidated Aircraft Corporation, who spoke on "Information Required for Installing Electrical Equipment in Aircraft"; and Fred Foulon (A '30) chief of equipment for the Douglas Aircraft Company, who spoke on "Radio Noise Elimination in Aircraft." Interest in electrical aspect of aircraft was indicated by an attendance of over 300 at this meeting.

Washington Section Meets

A capacity audience at the February 9 meeting of the Washington, D. C., Section of AIEE heard a talk on "Power for War" by C. M. Ripley, world traveler, author, and lecturer representing the General Electric Company. The program also included a motion picture, produced by the Westinghouse Electric and Manufacturing Company, showing the Japanese attack on Pearl Harbor and American industry's answer—mass production; and a travelogue motion picture in color of the Skagit River (Oreg.) Development in the Pacific Northwest. The program was preceded by a dinner at the Harrington Hotel.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE North Eastern district technical meeting, Pittsfield, Mass., April 8–9, and the South Western district technical meeting, Kansas City, Mo., April 28–30, 1943, and are expected to be ready for distribution in advance pamphlet form within the current month. The initials NE at the end of an abstract indicate that the paper will be presented at the North Eastern district meeting, SW that the paper will be presented at the South West district meeting. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Automatic Stations

43-64—A New Control System for Automatic Parallel Operation of Load Ratio Control Transformers; *S. Minneci* (*A '38*), *S. B. Farnham* (*M '42*). *20 cents.* The successful parallel operation of transformers equipped with automatic load-ratio control and line-drop compensation requires that stability of operation be insured. In addition, experience has shown that it is frequently highly desirable that other automatic features be included which will contribute toward operating flexibility and which will permit switching transformers in and out of parallel operation without disturbing the voltage level at the load center or causing an excessive initial circulating current at the instant of paralleling. This paper discusses the conditions which make these added features desirable, and presents a new control system whereby they all may be secured readily. In this new system, load current and circulating current are made to flow in separate paths in the control circuit, and each produces its effects independently, thereby insuring stable operation and maintaining the desired load-center voltage level. This separation of the load and circulating current, in conjunction with a modification in the closing circuit of the paralleling circuit breaker, also makes possible the avoidance of excessive initial circulating current when the breaker is closed. The simplicity and effectiveness of this arrangement in providing a fully automatic means for meeting all the anticipated operating requirements recommends its use in many applications. (NE).

Electrical Machinery

43-65—Use of Equivalent Annual Ambient Temperature in Overloading Transformers and Voltage Regulators; *M. S. Oldacre* (*M '42*). *15 cents.* The "Interim Report on Guides for Overloading Transformers and Voltage Regulators," prepared by the transformer subcommittee of the AIEE Committee on electrical machinery and published in AIEE *Transactions*, volume 61, 1942, September section, pages 692–4, referred to the use of equivalent annual ambient temperature instead of daily average ambient temperature in determining the overload possibilities of transformer apparatus. Previous methods for determining this equivalent temperature have been difficult to apply and therefore the Interim Report did not include a discussion of this point. The object of this paper on the use of equivalent annual ambient temperature in overloading transformers and voltage regulators is to point out a relatively simple method of calculating the equivalent annual ambient temperature from readily available climatological data for various locations in the country and also how this information may be applied in determining the overload possibilities of the transformer apparatus. (NE).

43-71—New Developments on Potential Transformer Design; *G. Camilli* (*M '27*). *15 cents.* The paper describes new designs of potential transformers in which volumes and weights have been reduced to a small fraction of the conventional designs, the factor of safety increased and this without any sacrifice in the accuracy characteristics. The designs are based on a novel method of arranging and insulating the high voltage winding. The new units are completely sealed (with no gaskets) and because of their small volume, it is economically advantageous to use special insulating liquid such as "Pyranol". Because of their small size and weight, it is possible to install these transformers in the bus structure near the high-voltage lines. (NE).

Industrial Control

43-74—Industrial Control: Dynamic Braking of a D-C Shunt Motor and Load; *G. F. Leland, L. T. Rader (A '34). 20 cents.* This paper presents an analysis of a shunt motor and attached load under dynamic braking conditions when the shunt field is held constant at full field. Three types of load are considered: (*a*) constant torque, (*b*) torque varying directly as the speed, together with a frictional component independent of the speed, (*c*) torque varying as the square of the speed together with a frictional component independent of the speed. For each case, equations are derived for current and time as a function of initial kinetic energy in the rotating system, initial watts in the dynamic braking resistor, and initial breaking current. For case (*a*) a family of curves is plotted where the ratio of friction to initial braking torque is varied from 0 to 100 per cent. For cases (*b*) and (*c*) families of curves are plotted for initial braking current equal to 100, 150, and 200 per cent of full load current, when the parameter, which is a ratio of friction to full load torque, varies from 0 to 100 per cent. All curves are plotted with dimensionless co-ordinates so that they may be applied to any size system. An example is given showing the use of the equation for case (*a*). (SW).

Land Transportation

43-67—The Sorocabana Railway Electrification; *Durval Muylaert. 30 cents.* The Sorocabana Electrification is noteworthy in that the railroad is a meter-gauge line run largely on wood fuel. The lack of suitable national coal or oil sources and the increasing difficulty of obtaining wood fuel led the railway to electrify its line between Sao Paulo and Santo Antonio. Rolling stock is outstanding in that the locomotives will be the most powerful 3,000-volt narrow gauge units ever built. The multiple-unit cars are the first 3,000-volt meter-gauge units to be used. The distribution system is designed to minimize the use of steel supports. Steel must be imported, and locally made concrete poles are to be utilized extensively. The power supply system using 3,000-volt mercury-arc rectifiers is the first installation in this hemisphere to use rectifier conversion with regenerative braking on locomotives. Regenerated energy returned to the substations will be dissipated in resistors roof-mounted at the several stations. (NE).

43-72—Train Communication; *L. O. Grondahl (M '42), P. N. Bassart. 25 cents.* The term, train communication, has gained use to designate communication between vehicles on a railway track and between such vehicles and stationary points, such as offices and towers. It has to do in all cases with railroad operation, and not with provision of communication facilities for passengers. A short history of the attempts to provide train communication is given. A system of telephonic communication in which a carrier current of low frequency is used is described. The rails on which the vehicles are located are used for the primary transmission line. The carrier frequency lies between 5,000 and 10,000 cycles. The paper discusses means of coupling to the track, the transmission characteristics of the track, the assistance that is gained from adjacent line wires, the characteristics of the transmitting and receiving apparatus, the current levels used in the track at the receiving and at the transmitting ends, and various devices that have been resorted to in order to provide a satisfactory transmission of intelligence under extremely difficult conditions. The relation of the communication system to railway operation and to other means of communication is discussed. (NE, SW).

43-75—Advantages of High-Speed Traction Motors; *C. A. Atwell (M '43). 15 cents.* Recent high-speed traction motors have certain inherent advantages over their slower speed predecessors. This paper lists these advantages and gives data on them, such as reduced size and weight, better commutation, simplified mechanical construction and mounting, and resulting simplified maintenance. The evolutionary trend toward higher-speed light traction motors started in the 20's but showed the most progress in the 30's. The recent designs that are available and in service on city and interurban transit vehicles and on some Diesel-electric and mining locomotives have saved large amounts of copper and steel. For example, the saving of over 600 tons of copper has been effected on motors for Presidents' Conference Committee street cars alone. The smaller and lighter weight motors make possible the construction of the modern vehicles on which they are used. (SW).

Power Generation

43-66—The Frequencies of Natural Power Oscillations in Interconnected Generating and Distribution Systems; *Reinhold Rüdenberg (M '38). 30 cents.* The transient distribution of power among the generator units, lines and consumers of interconnected systems, after any disturbance of the steady state, depends upon the characteristic data of the various elements of the entire network. Usually oscillations of power and of system frequency occur, which may be detrimental to the performance of the system or its parts. A method is developed for determining from a small number of well-known data the spectrum of natural frequencies of these oscillations and the distribution of their power swings among generators and motors. Generally a single very low frequency develops, determined by the interaction of all the speed governors and impressed upon the entire system. A group of higher frequencies arises, determined by the action of the synchronous generators and mainly disturbing these machines proper. A third group of highest frequencies is caused by the many induction motors, the inter-oscillations of which, however, are damped rapidly. Rules are derived in the paper for tuning the various elements in order to keep the more dangerous oscillations within narrow limits, improving the overall stability of the system. (NE).

Power Transmission, Distribution

43-73—Thermal Rating of Overhead Line Wire; *Myron Zucker (M '36). 25 cents.* Although normally of little practical importance, the thermal limitations of transmission and distribution circuits now are brought to the fore by scarcity of copper and aluminum. In this paper, new studies are added to thoroughly analyzed published and unpublished data. These are applied to the two major divisions: permissible temperatures to prevent the wire from deteriorating unduly and to preserve clearances; and temperatures that the wire will attain considering both the basic thermal relationships and the probable weather conditions under normal and emergency operation. On some of these points, detailed data are given, for example, information on time for annealing copper is taken from 37 authorities and put into simple form for engineering use. Other aspects, such as preservation of clearances and correlation of weather data, depend so much on local conditions that this paper suggests methods of treating them and gives examples, rather than trying to set a formula. (NE).

Protective Devices

43-69—Interim Report on Application and Operation of Circuit Breakers and Switchgear; *subcommittee on circuit breakers, switches, and fuses of the AIEE committee on protective devices. 15 cents.* The present war emergency makes it essential that maximum use be made of existing equipment and that a minimum amount of critical material be used for new equipment. To this end this report has been prepared as an aid to those involved in the application and operation of circuit breakers and switchgear. This report covers equipment of the following types:

1. A-c power circuit breakers above 600 volts, both indoor and outdoor. (AIEE Standard 19).
2. Air disconnecting switches. (AIEE Standard 22).
3. Switchgear assemblies. (AIEE Standard 27).

The report is a revision of the "Preliminary Report on Guides for Application and Operation of Circuit Breakers and Switchgear," by the subcommittee on breakers, switches, and fuses of the AIEE committee on protective devices, which was presented at the AIEE national technical meeting, January 28, 1943, New York, N. Y. It includes suggestions for making the maximum use of circuit breakers and switchgear by considering the effect of ambient temperature, artificial cooling, emergency loading, notification of existing equipment, and simplification of new installations. (NE).

43-70—Overvoltage Protection of Current Transformer Secondaries and Associated Circuits; *R. H. Kaufmann* (*M '41*), *G. Camilli* (*M '27*). *20 cents.* It long has been recognized that excessive potentials may be developed in current transformer secondaries under unusual conditions, such as open circuits. Recent experience discloses that dangerous overvoltages (several thousand volts) may be produced in the absence of circuit faults as a result of normal switching operations on circuits containing lumped capacitance. A simple procedure for circuit analysis and evaluation of approximate voltage magnitude for the switching transient case is reported. For easy reference, there are included tables of calculated secondary voltage magnitudes covering a broad range of application. Under certain conditions, overvoltage protection is desirable and important. Aside from the potential hazard to life, current transformer circuit insulation may be damaged, yet it may not be immediately evident. Performance at normal rated current may not be noticeably impaired, yet serious failures occur in the presence of fault current flow, thus nullifying the action of current actuated protective relays. The characteristics of a new overvoltage protector expressly designed for current transformer protection are presented. With this device current transformer secondary voltages are limited to moderate values. The protector is small and compact, and easily applied to existing as well as new current transformer installations. The characteristics are permanent, not affected by repetitive operation, and result in negligible ratio error in the normal operating current range. (NE).

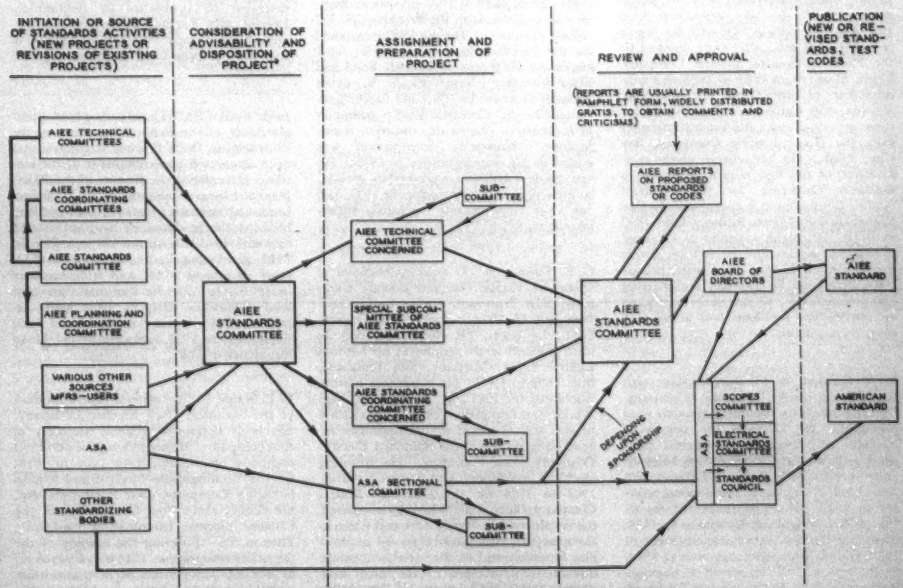
STANDARDS • • •

Procedure in Development of Standards Clarified

The AIEE standards committee is faced frequently with situations showing that many men engaged in various phases of standards development do not have a clear picture of the procedure involved. Standardization work is carried on by various technical committees of the Institute, by standards co-ordinating committees, and by sectional committees of the American Standards Association under the sponsorship of the AIEE. The diagram of standards activities, reproduced here indicates the inception or source, how the various projects are considered and assigned, and the steps taken in formulating standards and obtaining their review and approval prior to publication in final form as AIEE and American Standards. Certain special situations have been excluded in order not to complicate the diagram unnecessarily.

PERSONAL • • • •

E. S. McConnell (A '29, M '36) engineer with the Edison Electric Institute, New York, N. Y., has resigned to become product manager for aeronautical wires and cables with the United States Rubber Company, New York, N. Y. After receiving his bachelor of science degree in electrical engineering from the University of Minnesota in 1924, he was employed by the Chicago, Milwaukee and St. Paul Railway, Milwaukee, Wis., and Tacoma, Wash., as special apprentice and assistant engineer, from 1924 to 1928. During part of 1926 and 1927 he held the Strathcona Fellowship in transportation engineering at Yale University. In 1928 he was for a term instructor in railway mechanical engineering at Pennsylvania State College, State College. Later that year he was assistant electrical engineer for the American Brass Company, Waterbury, Conn., and from 1929 to 1933, was district engineer for the Anaconda Wire and Cable Company, Chicago, Ill. After a six-month period as sales engineer for the Air Conditioning Corporation, Chicago, Ill., he returned to the Anaconda company at Hastings-on-Hudson, N. Y., as mechanical and electrical designer of overhead transmission and distribution lines. He joined the Copper Wire Engineering Association,


INITIATION OR SOURCE OF STANDARDS ACTIVITIES (NEW PROJECTS OR REVISIONS OF EXISTING PROJECTS)
CONSIDERATION OF ADVISABILITY AND DISPOSITION OF PROJECT
ASSIGNMENT AND PREPARATION OF PROJECT
REVIEW AND APPROVAL
(REPORTS ARE USUALLY PRINTED IN PAMPHLET FORM, WIDELY DISTRIBUTED GRATIS, TO OBTAIN COMMENTS AND CRITICISMS)
PUBLICATION (NEW OR REVISED STANDARDS, TEST CODES
AIEE TECHNICAL COMMITTEES
AIEE STANDARDS COORDINATING COMMITTEES
AIEE STANDARDS COMMITTEE
AIEE PLANNING AND COORDINATION COMMITTEE
VARIOUS OTHER SOURCES MFRS—USERS
ASA
OTHER STANDARDIZING BODIES
AIEE STANDARDS COMMITTEE
AIEE TECHNICAL COMMITTEE CONCERNED
SUB-COMMITTEE
SPECIAL SUBCOMMITTEE OF AIEE STANDARDS COMMITTEE
AIEE STANDARDS COORDINATING COMMITTEE CONCERNED
SUB-COMMITTEE
ASA SECTIONAL COMMITTEE
SUB-COMMITTEE
AIEE REPORTS ON PROPOSED STANDARDS OR CODES
AIEE STANDARDS COMMITTEE
DEPENDING UPON SPONSORSHIP
AIEE BOARD OF DIRECTORS
ASA
SCOPES COMMITTEE
ELECTRICAL STANDARDS COMMITTEE
STANDARDS COUNCIL
AIEE STANDARD
AMERICAN STANDARD

Procedure in development of AIEE standards and test codes

Washington, D. C., in 1938 and in 1940 the Edison Institute. He holds several patents.

Burke Smith (A '17, M '28) transmission engineer, Illinois Bell Telephone Company, Chicago, retired on March 31, 1943. Born March 26, 1878, at Forrest, Ill., he received the degrees of bachelor of science in 1899, and doctor of philosophy in 1904 from Yale University. He was an instructor at Northwestern University, Evanston, Ill., during 1900–01, at Yale University, New Haven, Conn., during 1902–03, and at Purdue University, Lafayette, Ind., from 1904 to 1907. In 1903 he joined the New York (N. Y.) Telephone Company as an engineering assistant. From 1907 to 1911 he was an engineering assistant with the Chicago (Ill.) Telephone Company. He retained that position with the Central Group of Bell Telephone Companies until 1919, when he was made transmission engineer. Since 1920 he has been with the Illinois Bell Telephone Company. He is the author of a number of articles on mathematics, engineering, and education. He is also a fellow of the American Association for the Advancement of Science, and a member of the American Mathematical Society and Phi Beta Kappa.

S. L. Foster (A '96, M '96) superintendent of overhead lines, Market Street Railway Company, San Francisco, Calif., has retired. Born March 16, 1863, in Sacramento, Calif., he was graduated from Harvard University in 1885 with the degree of bachelor of arts. He was employed by the Thomson-Houston Electric Company, Lynn, Mass., from 1885 to 1888 as superintendent of installation in Michigan, Nevada, and California. In 1888 he became superintendent and general manager from the Home Electric Company, Bay City, Mich. He had charge of the construction of the first electric railroads in northern California for the Oakland (Calif.) Consolidated Railway, and the San Francisco, San Mateo Railway from 1890 to 1893. He began a period of 49 years' continuous service for the Market Street Railway in 1893. For many years he was chief electrician for railroad construction and maintenance. Of late years he worked on distribution problems and acted as a general consultant.

W. V. Kahler (M '39) chief engineer with the Illinois Bell Telephone Company, Chicago, has been appointed assistant vice-president. He received the degree of bachelor of science in mechanical engineering from the University of Missouri and joined the Bell Telephone Laboratories, New York, N. Y., as an engineering assistant in 1922. He was transferred to the Illinois Bell Telephone Company in 1924, becoming division equipment engineer in 1927, and division plant supervisor in 1930. From 1930 to 1937 he served as engineer for the American Telephone and Telegraph Company, New York, N. Y. He was made maintenance engineer in 1937. In 1938 he returned to the Illinois company as chief engineer. Since 1940 he has been also assistant director and construction secretary with the National Defense Advisory Committee.

L. H. Beebe (A '42) superintendent of tests, shop and test department, Southern California Edison Company Limited, Alhambra, has been named manager of the shop and test department of that company. At the outset of his career, he was employed by the General Electric Company, Schenectady, N. Y., from 1910 to 1914, as testman and salesclerk. He spent the years, from 1914 to 1918, as a meterman in the employ first, of the Los Angeles (Calif.) Gas and Electric Company and then the Nevada–California Power Company, Tonopah and Goldfield. He has been connected with the test department of the Southern California Edison Company since 1918, when he started as a polyphase testman. From 1920 to 1925 he was a technical assistant. In 1925 he was made assistant superintendent of the test department, and in 1928 superintendent of tests.

H. B. Robinson (M '38) operating superintendent of the Carolina Light and Power Company, Raleigh, N. C., has been elected a vice-president of that company. Mr. Robinson received his bachelor of engineering degree from North Carolina State College. From 1924 to 1927 he was an engineering assistant with the Brooklyn (N. Y.) Edison Company. During 1927 he worked for the Carolina Power company as relay engineer. He joined the Electric Bond and Share Company, New York, N. Y., as an assistant engineer in 1927 and in 1932 returned to the Carolina Power company as engineer in charge of substation maintenance. Substation construction was added to his responsibilities in 1935. He was made substation engineer for design, construction, and maintenance in 1937, and one year later became operating superintendent.

C. E. Young (A '09) assistant engineer of operation, Pacific Gas and Electric Company, San Francisco, Calif., has retired. Born July 16, 1874, in Santa Cruz County, Calif., he began his electrical career as third engineer in the employ of the Mutual Electric Light Company, San Francisco, from 1898 to 1900. He worked as marine machinist in 1901 for the Union Iron Works, San Francisco. From 1902 to 1904 he was shift foreman in the hydroelectric generating station of the Standard Electric Company, San Francisco. He installed electrical machinery and apparatus from 1904 to 1906 for the Diamond Match Company, Chico, Calif. In 1906 he entered the employ of the Pacific Gas and Electric Company. Until 1908 he served as division foreman, and in that year was made division superintendent. He held that position until 1914, when he joined the operation department.

J. H. Foote (A '18, F '32) supervising engineer of Commonwealth and Southern Corporation, Jackson, Mich., has been named to the Board of Registration for Architects, Professional Engineers, and Land Surveyors, of Michigan for a seven-year period. Mr. Foote was graduated from Michigan State College in 1914. Since 1915 he has been associated with affiliated companies now forming the Commonwealth and Southern Corporation. In various capacities he has been responsible for the design and construction of power distribution systems for the Eastern Michigan Power Corporation, Consumers Power Company, Stevens and Wood, Inc., and Allied Engineers, all of Jackson. In 1931 he was made supervising engineer for the Commonwealth and Southern Corporation.

G. E. Quinan (A '18, F '18) chief engineer of the Puget Sound Power and Light Company, Seattle, Wash., has been appointed chief consulting engineer with responsibility for all engineering activity of the company. Since 1911, when he became light and power operating superintendent for the Seattle (Wash.) Electric Company, its predecessor, he has been with the Puget Sound company. From 1913 to 1915 he was superintendent of the light and power department of that company. He was made engineer in charge of electrical and mechanical engineering in the Seattle district in 1915. In 1917 his duties were extended to properties in Bellingham, Everett, and Tacoma under the management of Stone and Webster, Philadelphia, Pa. He has been chief electrical engineer since 1919.

John Finlaw (A '35) assistant plant superintendent of the Schuylkill station of the Philadelphia (Pa.) Electric Company, has been appointed superintendent of the station. He entered the employ of the Philadelphia Electric Company in 1912. Before becoming assistant superintendent in 1940, he held the positions of assistant station operator in 1912, substation operator in 1913, generating station operator in 1914, chief electrician 1916, and shift engineer in 1917. In 1919 he was made assistant load dispatcher and, in 1922 load dispatcher. He became supervisor of load dispatchers in 1928, and assistant chief load dispatcher in 1931.

C. F. Nagle (A '39) general superintendent of the Scranton (Pa.) Electric Company, has been appointed general manager of that company. Before joining the Scranton company he worked, from 1904 to 1918, for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., the Pennsylvania Coal Company, and the Citizens Electric Illuminating Company, Pittston, Pa. Entering the employ of the Scranton company in 1918 as an engineer, he became superintendent of transmission and distribution in 1920. In 1926 he was made general superintendent.

Burkewood Welbourn (M '26) chief engineer, British Insulated Cables, Ltd., Prescot, England, has retired from that position to become consulting engineer and a member of the company's board of directors. Mr. Welbourn has been with British Insulated Cables, Ltd., since 1897, when he was appointed an assistant engineer. In 1901 he was made chief construction engineer, and in 1927 chief engineer. He received the honorary degree of master of engineering from the University of Liverpool in 1935, and is a member of the Institution of Electrical Engineers, London, England.

K. P. Applegate (A '14) general manager of the Hartford (Conn.) Electric Light Company, has been elected a vice-president of the company also. Receiving the degree of electrical engineer from Rensselaer Polytechnic Institute in 1912, he joined the Hartford Light company as a draftsman. In succession he became inspector of electrical apparatus in 1913, power sales engineer in 1914, and manager of the appliance and motor sales department in 1916. He was general purchasing agent from 1917 to 1929 when he became general manager.

John J. Anderson, Jr. (A '40) who joined the AIEE headquarters staff in 1940 to assist in the work of publishing the book "American Standard Definitions of Electrical Terms" has been granted a leave of absence to serve with the United States Naval Reserve. He will receive training on the USS Prairie State and upon completion will be commissioned an Ensign. Previous to his affiliation with the AIEE staff Mr. Anderson was employed by the United States Rubber Company, New York, N. Y.

W. J. McKeen (A '11, M '36) engineer of inside construction in the City Lighting Department of Seattle, Wash., recently retired. He was born on July 26, 1873, in Ontario. From 1898 to 1904 he did experimental work in electrical engineering and telephony in a private laboratory. Since 1904 when he became foreman on inside construction, he has been associated with the Seattle Lighting Department. In 1918 he was made engineer of inside construction with the duty of assisting the superintendent.

H. D. Moreland (A '35, M '41) district manager of Westinghouse X-ray Company, Portland, Oreg., has been made manager of the X-ray products, agency, and specialties department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He received the bachelor of science and master of science degrees in electrical engineering from the University of Oregon in 1930 and 1932. Since 1933 he has been employed by the Westinghouse X-Ray Company.

G. A. Mills (M '18) construction engineer, engineering department of the Central Power and Light Company, Corpus Christi, Tex., has been made superintendent of power plants. Mr. Mills has been associated with the Central Power company since 1939. Before that he held executive positions in a number of middle western utility companies. He was a charter member and first chairman of the AIEE Dallas Section, which was formed in 1928.

H. B. Stoddard (A '27) assistant engineer in the system engineering department, Consolidated Edison Company of New York (N. Y.), has been given a wartime leave of absence to become instrument engineer in the mechanical department of the General Cable Corporation, Perth Amboy, N. J. Mr. Stoddard has been with Consolidated Edison company since 1925 as general tester, and later junior engineer; in 1930 he was made assistant engineer.

J. J. Fiske, Jr. (A '42) student engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been made electronic control specialist for that company in the Los Angeles, Calif., area. He graduated from the University of California with the degree of bachelor of science in 1941 and entered the general sales department of the Westinghouse Electric and Manufacturing Company in that year.

William Wilson (M '23) retired assistant vice-president of Bell Laboratories Inc., New York, N. Y., has been awarded the medal of honor of the Institute of Radio Engineers for, "his achievements in the development of modern electronics, including its application to radio telephony, and for his contributions to the welfare and work of the Institute." For a fuller biography of Mr. Wilson see *Electrical Engineering*, February 1943, page 74.

Eugene Vinet (A '13, M '25) formerly electrical designer with Ebasco Services, Inc., New York, N. Y., has become special engineering assistant to the vice-president of W. L. Maxson Corporation, New York, N. Y. Mr. Vinet had been associated with Ebasco Services since 1941. Before that he was for a year executive secretary of the National Electrical Manufacturers Association.

W. S. Smith (A '34) traffic engineer, in the traffic engineering division of the South Carolina State Highway Department, Columbia, has been appointed to do traffic research work at Yale University, New Haven, Conn. Mr. Smith has been with the South Carolina Highway department since he received the degree of master of science in electrical engineering from the University of South Carolina, in 1933.

T. O. Eaton (A '28) switchgear specialist of the General Electric Company, Philadelphia, Pa., has been appointed assistant manager of sales, power transformer section, in the Pittsfield, Mass., works of that company. He entered the drafting department of the company's Schenectady, N. Y., works in 1925. He was transferred to Pittsburgh, Pa., in 1930 as switchgear specialist and to Philadelphia in 1938.

H. F. Dart (A '20, M '26) of the electronics tube engineering department, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., has been elected secretary of the New York section of the Institute of Radio Engineers and not national secretary of the Institute as was reported in *Electrical Engineering*, February 1943, page 76.

T. C. Clarke (A '35, M '42) district manager of the Northern Electric Company, Ltd., Vancouver, B. C., has been elected to the board of directors of that company. He joined the Northern Electric company in 1919 as sales engineer and was made a district sales manager (1928) for Manitoba. He was transferred to British Columbia in 1932.

C. R. Hanna (A '24, M '39) manager of the electromechanical department, research laboratories, of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded a citation of individual production merit by President Roosevelt for developing a device that increased the effectiveness of American tanks.

W. P. Graham (A '02, F '23) chancellor emeritus of Syracuse (N. Y.) University, has been awarded the honorary degree of doctor of laws by that University. He also has been elected a councilman-at-large of the city of Syracuse. A fuller biography of Doctor Graham was published in *Electrical Engineering*, October 1942, page 531.

F. J. Sullivan (A '17, M '41) division plant superintendent for the Michigan Bell Telephone Company, Saginaw, has been promoted to assistant general plant manager. He has been with the telephone company since 1905, and became division plant superintendent in 1919.

Dean A. Powers (A '42) formerly engineer with the Public Utilities Commission of Ohio, Columbus, has been appointed to the research staff of Battelle Memorial Institute, Columbus, Ohio. He will assist in electrochemical and electrometallurgical research.

J. F. Harrison (M '40) chief engineer of the Mississippi Power and Light Company, Jackson, has been elected president of the Mississippi Society of Professional Engineers. **J. B. Fountain** (A '35) engineer, has been elected secretary of the Mississippi society.

T. H. Crosby (M '37) district manager, Canadian Westinghouse Company, Ltd., Vancouver, B. C., has been appointed a member of the executive committee of the Association of Professional Engineers of British Columbia by the provincial government.

W. H. Mansfield (A '27) Louisiana plant superintendent, Southern Bell Telephone

Company, New Orleans, La., has been appointed general plant manager. Mr. Manafield has been with the telephone company since 1911.

F. F. Crocker (A '39) local agent of the California Electric Power Company, Palm Springs, has been made superintendent of that company's newly created district at Palm Springs. Mr. Crocker had been local agent since 1932.

J. D. Lawrence (A '25) district manager for the Appalachian Electric Power Company at Williamson, W. Va., has been transferred to Logan, W. Va., as division manager. Mr. Lawrence has been district manager since 1928.

H. R. Zimmerman (M '40) superintendent of the electrical department, Gary (Ind.) Sheet and Tin Mills, Carnegie-Illinois Steel Corporation, has been elected a director of the Association of Iron and Steel Engineers.

E. L. Robinson (A '28, M '30) sales manager of the Crescent Insulated Wire and Cable Company, Trenton, N. J., has been named chairman of the product scope committee of the National Electrical Manufacturers Association.

W. L. Smith (A '23) safety engineer of the Department of Water and Power of the City of Los Angeles, Calif., has been elected to the executive committee of the National Safety Council, Public Utilities Section.

L. G. McNeice (M '37) engineer and manager of the Orillia (Ont.) Water, Light and Power Commission, has been elected a district director of the Association of Municipal Electrical Utilities.

D. C. Green (M '26) chairman of the board of the Cleveland Pneumatic Tool Company, Ohio, has been awarded the honorary degree of doctor of engineering by Purdue University.

E. B. Whitman (M '34) partner in the firm of Whitman, Requardt and Smith, Baltimore, Md., has been elected president of the American Society of Civil Engineers for 1943.

W. C. White (A '23, M '30) director of the electronics laboratory, General Electric Company, Schenectady, N. Y., has been named a member of the board of directors of the Institute of Radio Engineers.

A. W. Bradt (M '26) secretary and general manager of the Hamilton (Ont.) Hydro-Electric System, has been elected a director of the Association of Municipal Electrical Utilities.

J. E. Teckoe, Jr. (M '29) manager of the Hydro-Electric Commission of Niagara Falls, Ont., has been elected a district director of the Association of Municipal Electrical Utilities.

T. H. Hogg (M '31, F '38) chairman and chief engineer, of The Hydro-Electric Power Commission of Ontario, Toronto, has been elected honorary president of the Ontario Municipal Electric Association.

L. R. Milburn (A '20, F '39) electrical engineer, Great Lakes Steel Corporation, Ecorse, Mich., has been elected a director of the Association of Iron and Steel Engineers.

Haraden Pratt (A '15, F '37) vice-president and chief engineer, Mackay Radio and Telegraph Company, New York, N. Y., has been elected secretary of the Institute of Radio Engineers.

R. B. Chandler (M '38) manager of the Public Utilities Commission, Port Arthur, Ont., has been elected president of the Association of Municipal Electrical Utilities.

C. J. Barker (M '37) major, Engineers Corps, United States Army, is now a lieutenant colonel on special duty in Great Britain.

G. A. Neal (A '19) president of the Sioux City Gas and Electric Company, Iowa, has been elected president of the Iowa Utilities Association.

C. A. Leland (M '27) president of the Des Moines Electric Light Company, Iowa, has been elected second vice-president of the Iowa Utilities Association.

OBITUARY • • • •

Stanton S. Hertz (A '17, M '27, F '39) vice-president and assistant to the president of the Copperweld Steel Company, Glassport, Pa., died on February 20, 1943. Born in Montgomery, Ala., on June 17, 1891, he received the degrees of bachelor of science in electrical engineering in 1911 and electrical engineer in 1926 from the Alabama Polytechnic Institute. From 1911 to 1916 he was foreman in the dynamo and transformer test departments of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1916 he was employed as an electrical engineer by the Electrical Engineering and Manufacturing Company, Pittsburgh, Pa. He served as an officer in the United States Army Corps of Engineers from 1917 to 1919, when he resumed his position as engineer and director of the Electrical Engineering company. In 1920 he was appointed district manager for the Stackpole Carbon Company, Pittsburgh, Pa., and later that year joined the Copperweld Steel Company as head of the electrical engineering department of the engineering division. He held the position of chief engineer in charge of the engineering division from 1927 to 1936. In 1936 he was named executive director of the Copper Wire Engineering Association, Washington, D. C. He returned to the Copperweld company in 1941 as vice-president. He was a member of the International Association of Electrical Inspectors, the International Association of Municipal Electricians, and the American Society of Testing Materials. From 1939 to 1942 he served on the AIEE membership committee.

Andrew Newton Outzen (A '14) superintendent of natural gas receiving station and the River Rouge manufacturing plant of the Michigan Consolidated Gas Company, Detroit, died August 26, 1941. He was born April 30, 1885, at Carlton, Wis., and was graduated from the University of Wisconsin with the degree of bachelor of science in electrical engineering in 1910. From 1908 to 1914 he was electrician for the University of Wisconsin, Madison. In 1912 he entered the engineering department of the Madison (Wis.) Gas and Electric Company, becoming superintendent of its gas works in 1914. In that same capacity he worked for the Binghamton (N. Y.) Gas Company from 1915 to 1917. In 1917 he joined the Michigan Consolidated Gas Company as production foreman at Station *A* in Detroit. In 1918 he was made superintendent and in 1919 superintendent of manufacturing. In 1920 he became superintendent of construction and operation at Station *J*. He was first associated with the company's River Rouge plant in 1924 as superintendent of design. In rapid succession he served as certifying engineer on construction in 1925 and superintendent in 1926. He returned to the position of superintendent of Station *J* in 1927, and was again superintendent of the River Rouge plant from 1929 to 1933. He held both positions from 1933 to 1937. In 1936 he was appointed superintendent of the natural gas receiving station.

Andrew John O'Reilly (A '03) retired construction safety engineer of St. Louis, Mo., died on January 27, 1943. Born on January 13, 1863, in Montgomery County, Mo., he was graduated from Washington University in 1888 with the degree of bachelor of engineering. After operating his own electrical engineering firm for a short time, he entered the employ of the Municipal Electric Light and Power Company, St. Louis, Mo., as assistant to the general manager to superintend electrical construction. In 1890 he was made supervisor and chief electrical engineer. From 1903 to 1905 he was chief of fire prevention for the Louisiana Exposition. He acted as president of the Board of Public Improvement, St. Louis, Mo., from 1905 to 1909. After 1909 he worked as a consulting engineer. He had charge of the construction of the St. Louis (Mo.) station of the Mississippi River Power Distribution Company in 1912 and 1913. As a safety engineer he was associated with the National Fire Prevention Board. He served on the Public Service Commission of the State of Missouri from 1921 to 1925. From 1926 to 1932 he was chief electrical engineer for the Department of Public Safety of the City of St. Louis (Mo.). He was also a member of the American Association for the Advancement of Science, and the American Society of Mechanical Engineers.

Elmer H. Schwarz (A '03, M '18) consulting engineer of the firm of Schwarz, Hughes, and McCarthy, New York, N. Y., died on February 21, 1943. Born in Rochester, N. Y., on February 23, 1880, he received the degree of bachelor of philosophy from the Sheffield Scientific School of Yale University in 1901. From 1901 to 1903 he worked in the testing, drafting, and a-c engineering departments of the General Electric Company, Schenectady, N. Y. His career in patent work began in 1904, when he joined the Patent Control Board, New York, N. Y., which handled the patent interests of the General Electric Company and the Westinghouse Electric and Manufacturing Company. From 1911 to 1940 he was a partner in the firm of Hammer and Schwarz, New York, N. Y., consulting electrical and mechanical engineers. In 1940 he became a member of the firm of Schwarz, Hughes, and McCarthy. He held a number of patents and was also a member of the American Society of Mechanical Engineers, the American Society of Refrigerating Engineers, and the Society of Automotive Engineers. For many years he served as a director of the Henry Street Settlement, New York, N. Y.

Robert Stuart Stewart (A '96, M '00) consulting electrical engineer of La Jolla, Calif., died November 11, 1942. Born September 10, 1869, in Detroit, Mich., he received the degrees of bachelor of arts in 1891, and master of arts and electrical engineer in 1894 from Princeton University. In 1894 he began a six-year affiliation with the Public Lighting Commission of Detroit (Mich.). He supervised the installation of cables and terminals on the street lighting system, and later took general charge of the distribution system. He resigned in 1896, and after a year of study in Europe, joined the Westinghouse Electric and Manufacturing Company, as erecting engineer in charge of that company's exhibit at Omaha, Neb. During 1899 he supervised construction for the Westinghouse Company near Philadelphia, Pa. From 1900 to 1904 he was employed by the British Westinghouse Electric and Manufacturing Company, Manchester, England, as engineer in charge of the design of all d-c generators and motors. He was engaged in the purchase and consolidation of several power companies in Essex County, Ont., from 1904 to 1918. Since 1918 he had practiced as a consulting engineer.

Martin Schiff (M '20, F '39) chief engineer, Century Electric Company, St. Louis, Mo., died on February 15, 1943. He was born on October 7, 1890, in New York, N. Y., and received the degree of mechanical engineer from Cornell University in 1912. That year he entered the employ of the Diehl Manufacturing Company, Elizabeth, N. J., as test engineer, and in 1913 became assistant engineer for the Ideal Electric and Manufacturing Company, Mansfield, Ohio. He was a member of the firm of Schiff and Schroeder, New York, N. Y., manufacturers of hoisting machinery, during 1914. In 1915 he returned to the Ideal Electric company. Following service in the United States Navy during World War I, he was engaged in a-c motor design for the Electro Dynamic Company, Bayonne, N. J., during 1920. From 1920 to 1929 he was assistant chief engineer and chief engineer with Roth Brothers and Company, Chicago, Ill. He was made assistant chief engineer and assistant to the president for the Imperial Electric Company, Akron, Ohio, in 1929. In 1933 he joined the Century company as chief engineer.

Albert Holloway Reiber (A '21, M '35, F '40) engineer of development and research, Teletype Corporation, Chicago, Ill., died on February 1, 1943. He was born in New York, N. Y., on April 13, 1894, and was graduated from the Stevens Institute of Technology with the degree of mechanical engineer in 1916. Since 1916 he had been active in the development of printing telegraph equipment, in which connection he was issued numerous patents. From 1916 to 1920 he was employed by the Western Union Telegraph Company as a development engineer. In 1920 he joined the Kleinschmidt Electric Company, Long Island City, N. Y., which became the Mokrum-Kleinschmidt Corporation in 1925 and the Teletype Corporation in 1928. Until 1922 when he became manager of sales and engineering, he served as sales engineer. He was transferred to Chicago, Ill., as development engineer in 1925, and in 1928 was made apparatus engineer and assistant to the vice-president. In 1930 he was appointed engineer of development and research. He was a member of Tau Beta Pi.

Thomas Reeve Rosebrugh (A '91) professor emeritus of electrical engineering of the University of Toronto, died on January 24, 1943. Born in Ontario, on June 6, 1866, he received the degrees of bachelor of arts in 1877 and master of arts in 1893 from the University of Toronto. The honorary degree of doctor of science was conferred upon him by that University in 1936. He joined the faculty of the school of practical science of the University of Toronto, Ont., as a lecturer in electrical engineering in 1889, and was appointed head of the department of electrical engineering a few years later. He remained in that position until his retirement in 1936. In collaboration with his father he invented, in 1894, one of the early "phantom circuit" systems for telephone and telegraph communication. He was the author of papers on electrochemistry, transmission calculations, and quantic determinants. He was an organizer of the Toronto Section of AIEE, a charter member of the Toronto section of the Institute of Radio Engineers, and a fellow of the Royal Society of Canada.

Joseph Francis Stockwell (A '03) executive vice-president of the Keystone Telephone Company, Philadelphia, Pa., died on January 28, 1943. Mr. Stockwell, who was born on February 29, 1880, at Portland, Maine, graduated from the Drexel Institute of Technology. He entered the engineering department of the Keystone company in 1900 as a draftsman. In 1902 he was made wire chief of the main exchange. From 1903 to 1906 he was on leave of absence to aid in developing the Ontario Telephone Company, Oswego, N. Y., and the Independence Telephone Company, Syracuse, N. Y. In 1906 he returned to the Keystone company, becoming a director, executive vice-president, and general manager. He also held the positions of director and vice-president of the Camden (N. J.) and Atlantic Telephone Company and the Pennsylvania Independent Telephone Association. He was a director of the Chamber of Commerce and Board of Trade of Philadelphia, as well as a member of the Telephone Pioneers of America, and a number of historical societies.

John G. Barry (A '03) retired honorary vice-president of the General Electric Company, Schenectady, N. Y., died on March 4, 1943. Born on December 4, 1868, Mr. Barry joined the Thomson-Houston Electric Company, Lynn, Mass., in 1890, and began a lifetime affiliation with that company and its successor, the General Electric Company. In 1894 he transferred to the railway department at Schenectady, N. Y. He was appointed department manager in 1907 and in 1917 assumed the additional duties of general sales manager. In 1922 he was named vice-president charged with supervision of the apparatus sales organization. He retired with an honorary vice-presidency in 1935. For many years he served on the executive committee of the American Electric Railway Association. He had served also as a member of the Schenectady Board of Education and as fuel administrator for the Schenectady district during World War I. He was also a member of the Schenectady Chamber of Commerce.

Delbert C. Meyer (M '29) toll equipment engineer, Bell Telephone Laboratories, New York, N. Y., died on February 2, 1943. Born in Cleveland, Ohio, on August 6, 1890, he received the degrees of bachelor of arts from Western Reserve University and bachelor of science from the Case School of Applied Science in 1912. He immediately entered the engineering department of the Western Electric Company, Chicago, Ill., where in 1917 he was placed in charge of the design of telephone central office equipment. In 1920 he was transferred to the New York (N. Y.) engineering department of that company. When the Bell Telephone Laboratories were formed in 1925, he became head of the toll equipment department, responsible for solving the design problems for many parts of the telephone systems, cable and coaxial systems, and all telegraph systems. He published articles on equipment and held

several patents. Mr. Meyer was serving on the AIEE membership committee for 1942–43.

Henry O'Brien Frederick Hayward (A '39) captain in the Royal Canadian Armed Forces, died on January 15, 1943, in Poona, India. He was born on March 30, 1913, in Vancouver, B. C., and was graduated from Brasenose College, Oxford University, with a bachelor of arts honors degree in engineering in 1935. From 1932 to 1937 he was associated with Metropolitan-Vickers Electrical Company, Manchester, England, where he was employed first as a student apprentice, later becoming designer of a-c and d-c machines and mining equipment, and sales representative. During 1935 he headed an Oxford University expedition to explore Greenland. In 1937 he entered the electrical construction and maintenance department of the British Columbia Electric Railway Company, Vancouver, as assistant test engineer. He was a graduate member of the Institute of Electrical Engineers, London, England, and a fellow of the Royal Geographical Society.

James Thomas Holmes (M '24) engineer with the Frink Corporation, Long Island City, N. Y., died on February 12, 1943. He was born on May 6, 1880, in Washington, D. C. From 1899 to 1907 he worked as electrical helper, journeyman, and foreman, on the electrical construction in buildings in New York, N. Y. He was an electrical inspector for the City of New York during 1907 and 1908 and for the Metropolitan Life Insurance Company, New York, N. Y., from 1908 to 1910. As superintendent of installation and construction, he joined I. P. Frink, Inc., New York, N. Y., in 1910. He was made chief electrical engineer in 1913. In 1935 he resigned his position to become president of Mitchell-Vance Company, New York, N. Y. In 1939 he returned to the Frink Corporation where he worked on special lighting problems. He served on the AIEE committee on the production and application of light from 1933 to 1936.

Ludwig Kallir (M '29) of the British Electrical and Allied Industries Research Association, London, England, died on January 7, 1943. Born November 11, 1874, in Leipzig, Germany, he attended the Technische Hochschule, Vienna, Austria. He taught at that institution from 1897 to 1900. In 1900 he joined the Union Elektrizitats-Gesellschaft, Vienna, the Austrian organization of the Allgemeine Elektrizitats-Gesellschaft. He served as director responsible for the department of power generation and transmission from 1910 to 1938. In the latter year he was made a member of the board of directors of the union. He was president of the Elektrotechniacher Verein in Vienna and of the Austrian committee of electrical engineers. In 1939 he moved to London, and in 1941 he became associated with the British Electrical and Allied Industries Research Association.

Lauren Dale Nordstrum (A '04, M '13) designing engineer in the d-c motor generator department, General Electric Company, Fort Wayne, Ind., died February 1, 1943. He was born February 23, 1878, in Rainsville, Ind., and was graduated from Purdue University in 1901 with the degree of bachelor of science in electrical engineering. He was engaged as an instructor of physics at Purdue University, Lafayette, Ind., from 1901 to 1905. In 1905, as an engineer in the test department, he began a 37-year association with the General Electric Company. The same year he was transferred to the position of design engineer in the apparatus department. In 1918 he was made assistant engineer of that department. In 1925 he became engineer in the d-c apparatus section, where he was responsible for improvements in electric dynamometers and hydraulic dynamometers.

John A. Gallagher (A '42) equipment engineer, Southern Bell Telephone and Telegraph Company, Atlanta, Ga., died November 11, 1942. He was born June 21, 1885, at St. Louis, Mo. From 1906 to 1917 he worked for the Kinloch Telephone Company, St. Louis, Mo., the Abilene (Tex.) Telephone Company, and the Atlanta Telephone Company. In 1917 he was employed as equipment engineer in the engineering department of the Western Electric Company, Chicago, Ill. He became equipment supervisor for the Southern Bell company in Savannah, Ga., in 1920. Transferring in 1925 to that company's Florida division at Jacksonville he held the positions of equipment engineer, division equipment engineer, and maintenance supervisor until 1941. In the latter year he moved to the chief engineer's office, Atlanta, Ga., as equipment engineer.

Arthur C. Flory (M '26) manager of the steam turbine department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died on March 1, 1943. Born February 14, 1883, he graduated from Lehigh University in 1906 with the degree of mechanical engineer. He immediately entered the steam turbine department of the Allis-Chalmers company as a draftsman. In 1909 he became engineer in the department. From 1912 to 1919 he was assistant manager. Since 1919 he had held the position of manager of the department. The steam turbine department was responsible for the engineering and sales of all steam turbine units. He was also a member of the American Society of Mechanical Engineers. From 1938 to 1941 he served on the AIEE Lamme Medal committee.

Edward Engel Hilbert (A '42) engineer, motor engineering department, Wagner Electric Corporation, St. Louis, Mo., died on February 26, 1943. Born in St. Louis, Mo., on May 20, 1913, he was graduated from Washington University in 1935 with the degree of bachelor of science in electrical engineering. In 1936 he entered the employ of the Wagner company, where he worked on the design and writing of specifications for integral horsepower motors.

MEMBERSHIP ..

Recommended for Transfer

The board of examiners, at its meeting on March 18, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Boehne, E. W., research engineer, General Electric Company, Philadelphia, Pa.

Dobson, W. P., chief testing engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont., Canada.

Hughes, M. C., head of Electrical Engineering department, Agricultural and Mechanical College of Texas, College Station, Texas.

Lane, R. K., president, Public Service Company o Oklahoma, Tulsa, Okla.

Logan, K. H., chief, Underground Corrosion Section, National Bureau of Standards, Washington, D. C.

Thomas, J. B., president and general manager, Texas Electric Service Company, Fort Worth, Texas.

6 to grade of Fellow

To Grade of Member

Arnott, Clarence, assistant superintendent, British Columbia Electric Railway Company, Vancouver, B. C., Canada.

Backer, C. M., senior engineer, Radio Signal Corps, Wright Field, Dayton, Ohio.

Barnes, P. C., switchgear engineer, Canadian General Electric Company Limited, Toronto, Ont., Canada.

Bennett, H. G., electrical engineer, Durham Public Service Company, Durham, N. C.

Braam, A. E., engineer, Northern Indiana Public Service Company, Hammond, Ind.

Dixon, H. S., electrical test engineer, Douglas Aircraft Company, Los Angeles, Calif.

Evans, R. L., electrical design engineer, Mason and Hanger Company, Baraboo, Wis.

Fink, G. R., switchgear section, General Electric Company, Philadelphia, Pa.

Goldsborough, S. L., design engineer, Westinghouse Electric and Manufacturing Company, Newark, N. J.

Hallman, T. R., relay engineer, Detroit Edison Company, Detroit, Mich.

Hanna, W. M., assistant to electrical engineer, Consolidated Gas Electric Light and Power Company, Baltimore, Md.

Kisner, A. G., central station engineer, General Electric Company, Philadelphia, Pa.

Kresser, J. V., district engineer, Westinghouse Electric and Manufacturing Company, San Francisco, Calif.

LaPierre, C. W., development engineer, General Electric Company, Schenectady, N. Y.

Light, P. H., application engineer, General Electric Company, Schenectady, N. Y.

Love, R. M., electrical engineer, Durham Public Service Company, Durham, N. C.

Lynn, G., manager, D.C. generator engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Mars, Nick, laboratory engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Moody, A. F., division testing and regulating chief, Western Union Telegraph Company, Dallas, Texas.

Muller, H. N., central station engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Newhouse, R. C., member of technical staff, Bell Telephone Laboratories, Inc., New York.

Piepho, E. E., electrical engineer, Detroit Edison Company, Detroit, Mich.

Powell, J. B., engineer, General Electric Company, New Haven, Conn.

Smith, E. L., electrical engineer, The Firestone Tire and Rubber Company, Akron, Ohio.

Smith, R. J., vice-president, American Electrical Construction Company, Inc., Philadelphia, Pa.

Sykes, C. S., district engineer, Philadelphia Electric Company, Philadelphia, Pa.

Titter, B. K., chief electrical engineer, Nicaro Nickel Company, New York.

Weinheimer, C. M., in charge of mechanical division, Detroit Edison Company, Detroit, Mich.
28 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before April 30, 1943, or June 30, 1943, if the applicant resides outside of the United States or Canada.

To Grade of Member

Benjamin, E. C., M. W. Kellogg Co., New York, N. Y.
Berry, W. L., Hughes Aircraft Co., Culver City, Cal.
Blum, H. L., Royal Switchboard Co., Brooklyn, N. Y.
Boorshtosky, N. P. (Member re-election), Moloney Elec. Co., St. Louis, Mo.
Breckenridge, F., W. E. & M. Co., Mansfield, O.
Brodie, L. S., Canadian Army, Directorate of Mechanical Maintenance, MGO Branch, NDHQ, Ottawa, Ont.
Burden, B. C., U. S. Ind. Tel. Co., Washington, D. C.
Cockrell, W. D., Gen. Elec. Co., Schenectady, N. Y.
Coller, G., Penn. Power & Light Co., Shenandoah, Pa.
Crawford, K. B., Rural Elec. Adm., St. Louis, Mo.
Doherty, J. P., Quality Elec. Co., Los Angeles, Cal.
Eldridge, T. L., Jr., Electric Service Supplies Co., Philadelphia, Pa.
Farmer, S. G., Elec. Constr. Co., Ltd., Bushbury Engg. Works, Bushbury, Wolverhampton, Eng.
Foulk, T. M., Pub. Serv. Co., Denver, Col.
Herzog, E. J., Westinghouse Elec. Int. Co., Caracas, Venezuela, S. A.
Impellitteri, V. J., Bur. of Ships, Navy Dept., Washington, D. C.
Lent, S. (Member), Boston Elev. Ry., Boston, Mass.
Lillyblad, R. H., Camfield Mfg. Co., Grand Haven, Mich.
Mackey, B. R., Cornell Univ., Ithaca, N. Y.
Marchese, V. J., E. I. du Pont De Nemours Co., Wilmington, Del.
Michelsen, J. H., M. W. Kellogg Co., New York, N. Y.
Miller, C. E., Commonwealth Edison Co., Chicago, Ill.
Mundt, A. J., Western Union Tel. Co., New York, N. Y.
O'Connor, R. R., Ill. Bell Telephone Co., Chicago, Ill.
Olken, H., Navy Yard, Washington, D. C.
Pixton, S. W., Mtn. States Tel. & Tel. Co., Salt Lake City, Utah.
Platt, N. L., Cornell Univ., Ithaca, N. Y.
Rigby, W. S., Ordnance Dept., Tank Automotive Center, Detroit, Mich.
Sliter, H. M., Gen. Elec. Co., New York, N. Y.
Steele, D. R., Stone & Webster Engg. Corp., Long Beach, Cal.
Thor, B. V., Canadian Westinghouse Co., Hamilton, Ont.
Underhill, E. M., Cinaudagraph Corp., Stamford, Conn.
White, P. A., Penn. Power & Light Co., Shenandoah, Pa.
Winther, J. B., Dynamatic Corp., Kenosha, Wis.
Wolfe, I. D., Pacific Bridge Co., Pearl Harbor, T. H.
Wright, H. M., A. Reyrolle & Company, Limited, Hebburn-on-Tyne, County Durham, England.
Zink, G. W., Phelps Dodge Copper Prod. Corp., Yonkers, N. Y.
37 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Adams, L. P., Gen. Elec. Co., Schenectady, N. Y.
Ahern, C. R., Mass. Inst. Tech., Boston, Mass.
Allen, T. E., Gen. Elec. Co., Schenectady, N. Y.
Almasy, G. W., Gen. Elec. Co., Schenectady, N. Y.
Ball, E. G., Bethlehem Steel Co., Lackawanna, N. Y.
Baucom, I. C., Jr., Gen Elec. Co., Schenectady, N. Y.
Bentley, A. Y., Mass. Inst. Tech., Cambridge, Mass.
Blum, P. F., Gen. Elec. Co., Lynn, Mass.
Borden, L. L., Gen. Elec. Co., Schenectady, N. Y.
Bornstein, L., Gen. Elec. Co., Schenectady, N. Y.
Broome, J. W., Gen. Elec. Co., Schenectady, N. Y.
Brown, D. R., Gen. Elec. Co., Schenectady, N. Y.
Browne, A. J., Bethlehem Steel Corp., Buffalo, N. Y.
Burwell, T. J., United Ill. Co., New Haven, Conn.
Butler, G. H., Gen. Elec. Co., Schenectady, N. Y.
Casperson, N., Gen. Elec. Co., Schenectady, N. Y.
Chelgren, A. E., Lt. Signal Corps, U. S. Army, Cambridge, Mass.
Chow, W. T., Gen. Elec. Co., Schenectady, N. Y.
Cohn, S. B., Harvard Univ., Cambridge, Mass.
Cooper, O. L., Jr., Gen. Elec. Co., Schenectady, N. Y.
Critchlow, G. F., Cornell Univ., Ithaca, N. Y.
Dean, R. K., Gen. Elec. Co., Schenectady, N. Y.
DesRoberts, H. J., DesRoberts Elec. Co., Lynn, Mass.
Dunham, S. B., Gen. Elec. Co., Schenectady, N. Y.
Flamm, H. F., Gen. Elec. Co., Schenectady, N. Y.
Flower, R. L., Gen. Elec. Co., Schenectady, N. Y.
Frank, E., Curtiss-Wright Corp., Buffalo, N. Y.
Friedl, E. N., Gen. Elec. Co., Schenectady, N. Y.
Fritsche, W. O., United Illuminating Co., New Haven, Conn.
Fuegel, E. F., Gen. Elec. Co., Pittsfield, Mass.
Gayer, J. H., Signal Corps, U. S. Army, Cruft Lab., Harvard Univ., Cambridge, Mass.
Geiszler, A. R., Gen. Elec. Co., Schenectady, N. Y.
Glasford, G. M., Mass. Inst. Tech., Cambridge, Mass.
Golombe, S. N., Mass. Inst. Tech., Cambridge, Mass.
Guyer, E. H., Bethlehem Steel Corp., Lackawanna, N. Y.
Haertig, M. M., Gen. Elec. Co., Schenectady, N. Y.
Hall, D. F., Gen. Elec. Co., Schenectady, N. Y.
Hang, D. F., Gen. Elec. Co., Schenectady, N. Y.
Hickey, J. S., Jr., Gen. Elec. Co., Schenectady, N. Y.
Huelsman, A. H., Gen. Elec. Co., Schenectady, N. Y.
Illman, R. W., Mass. Inst. Tech., Cambridge, Mass.
Imm, R. A., Gen. Elec. Co., Schenectady, N. Y.
Jacox, W. R., Gen. Elec. Co., Schenectady, N. Y.
Kessler, G. W., Gen. Elec. Co., Schenectady, N. Y.
Klemm, G. H., Harvard University, Cambridge, Mass.
Koehler, R. A., Gen. Elec. Co., Schenectady, N. Y.
Kratz, E. M., Gen. Elec. Co., Schenectady, N. Y.
Kruse, W. R., Gen. Elec. Co., Schenectady, N. Y.
Kusko, A., Mass. Inst. Tech., Cambridge, Mass.
Larsen, R. B., Gen. Elec. Co., Schenectady, N. Y.
Lawrence, B. J., Gen. Elec. Co., Bridgeport, Conn.
Leete, B. D., Gen. Elec. Co., Schenectady, N. Y.
Lewis, R. V., Gen. Elec. Co., Schenectady, N. Y.
Light, E. E., Gen. Elec. Co., Schenectady, N. Y.
Love, A. L., III, Gen. Elec. Co., Bridgeport, Conn.
Mauer, A., Gen. Elec. Co., Schenectady, N. Y.
Mayclin, C., Gen. Elec. Co., Schenectady, N. Y.
McClure, R. C., Gen. Elec. Co., Schenectady, N. Y.
McDonnell, J. A., Gen. Elec. Co., Schenectady, N. Y.
Meloun, G. J., Gen. Elec. Co., Schenectady, N. Y.
Mitchel, W. E., Gen. Elec. Co., Schenectady, N. Y.
Mitchell, F. A., Stromberg Carlson Tel. Mfg. Co., Rochester, N. Y.
Moffett, H. R., Gen. Elec. Co., Schenectady, N. Y.
Morgan, R. E., Gen. Elec. Co., Schenectady, N. Y.
Mullen, F. C. (Associate re-election), Siena College, Loudonville, N. Y.
Myers, R. T., Gen. Elec. Co., Schenectady, N. Y.
Nelson, V. T., Jr., Elec. Co., West Lynn, Mass.
Oakley, W. J., United Illuminating Co., New Haven, Conn.
O'Neil, S. J., Gen. Elec. Co., Schenectady, N. Y.
Owens, R. M., Gen. Elec. Co., Lynn, Mass.
Parker, R. J., Gen. Elec. Co., Schenectady, N. Y.
Peel, J. A., Gen. Elec. Co., Schenectady, N. Y.
Phillips, J. E., Gen. Elec. Co., Schenectady, N. Y.
Popp, F. F., Stromberg Carlson Tel. Mfg. Co., Rochester, N. Y.
Port, R. F. (Associate re-election), Central New York Pr. Corp., Syracuse, N. Y.
Potthoff, H. J., Gen. Elec. Co., Schenectady, N. Y.
Pratt, F. E., Stromberg Carlson Tel. Mfg. Co., Rochester, N. Y.
Ratliff, C. M., Jr., Gen. Elec. Co., Schenectady, N. Y.
Reed, R. D., Gen. Elec. Co., Schenectady, N. Y.
Reilly, T. J., Gen. Elec. Co., Schenectady, N. Y.
Rich, G. S., Gen. Elec. Co., Pittsfield, Mass.
Royce, H. W., Mass. Inst. Tech., Cambridge, Mass.
Rubel, J. H., Gen. Elec. Co., Schenectady, N. Y.
Sanderford, R. M., Jr., Gen. Elec. Co., Schenectady, N. Y.
Schauss, S. L., Cornell Univ., Ithaca, N. Y.
Schneider, R. C., Gen. Elec. Co., West Lynn, Mass.
Scholz, H. K., Gen. Elec. Co., Schenectady, N. Y.
Schroeder, G. W., Gen. Elec. Co., Schenectady, N. Y.
Shoffner, J. M., Harvard Univ., Cambridge, Mass.
Smith, J. H., Gen. Elec. Co., Bridgeport, Conn.
Smith, R. E., Gen. Elec. Co., Schenectady, N. Y.
Snider, G. B., Jr., Gen. Elec. Co., Schenectady, N. Y.
Squier, C. L., Bethlehem Steel Co., Lackawanna, N. Y.
Stavely, E. B., Jr., Gen. Elec. Co., Schenectady, N. Y.
Stone, J. A., Gen. Elec. Co., Schenectady, N. Y.
Tang, M. C., Gen. Elec. Co., Pittsfield, Mass.
Terrill, S. F., Nash Engg. Co., So. Norwalk, Conn.
Thor, D. D., Gen. Elec. Co., Schenectady, N. Y.
Tillma, J. E., Gen. Elec. Co., Schenectady, N. Y.
Van Horn, I. H., Jr., Mass Inst. Tech., Cambridge.
Verzuh, F. M., Mass. Inst. Tech., Cambridge, Mass.
Wheeler, B. G., Gen. Elec. Co., Schenectady, N. Y.
Wilcox, G. R., Gen. Elec. Co., Schenectady, N. Y.
Wilson, F. D., Jr., Gen. Elec. Co., Schenectady, N. Y.

2. MIDDLE EASTERN

Anderson, R. L., W. E. & M. Co., East Pittsburgh, Pa.
Arnold, N. R., R. C. A. Mfg. Co., Camden, N. J.
Ballard, R. J., W. E. & M. Co., East Pittsburgh, Pa.
Beers, M. I., Robbins & Myers Inc., Springfield, O.
Behrent, L. F., U. S. Civil Service Comm., Washington, D. C.
Bennett, E. G., Nat. Bureau of Standards, Washington, D. C.
Bradford, E. L., W. E. & M. Co., East Pittsburgh, Pa.
Brewer, E. W., Gen. Elec. Co., Erie, Pa.
Brown, D. J., Gen. Elec. Co., Philadelphia, Pa.
Browning, E. H., Jr., W. E. & M. Co., East Pittsburgh, Pa.
Burdett, J. C., W. E. & M. Co., Lima, O.
Call, R. D., W. E. & M. Co., East Pittsburgh, Pa.
Carr, J. W., W. E. & M. Co., East Pittsburgh, Pa.
Carr, W. J., Jr., Westinghouse Res. Lab., East Pittsburgh, Pa.
Catanzaro, J., Westinghouse Elec. Co., Baltimore, Md.
Chapman, C. W., Gen. Elec. Co., Erie, Pa.
Christensen, W. L., W. E. & M. Co., East Pittsburgh, Pa.
Connelley, R. K., Philadelphia Company, Pittsburgh, Pa.
Crockford, J. B., W. E. & M. Co., Lima, O.
Crowe, P. F., U. S. Engr's, Dayton, O.
Darchuk, W., 4013 Buechner Ave., Cleveland, O.
DeArcangelis, F. A., W. E. & M. Co., East Pittsburgh, Pa.
Doerrie, C. C., W. E. & M. Co., East Pittsburgh, Pa.
Dufly, P. A., Jr., W. E. & M. Co., Baltimore, Md.
Ebert, T. E., W. E. & M. Co., East Pittsburgh, Pa.
Evenson, H. J., W. E. & M. Co., East Pittsburgh, Pa.
Feuerriegel, R. G., Gen. Elec. Co., Philadelphia, Pa.
Florence, V. H., Philco Corp., Philadelphia, Pa.
Frink, R. E., W. E. & M. Co., East Pittsburgh, Pa.
Gable, N. P., Sylvania Electric Products, Inc., Emporium, Pa.
Grafe, J. H., III, Gen. Elec. Co., Philadelphia, Pa.
Granneman, A. H., Bur. of Ships, Navy Dept., Washington, D. C.
Gurney, J. R., Jr., W. E. & M. Co., Cleveland, O.
Halma, H., R. C. A. Serv. Co., Philadelphia, Pa.
Harris, W. W., Bethlehem Steel Corp., Lebanon, Pa.
Helsel, W. D., Jr., Gen. Elec. Co., Erie, Pa.
Hershfield, S., Philco Radio & Television Corp., Philadelphia, Pa.
Himmer, F., Philco Radio & Tel. Corp., Philadelphia, Pa.
Hoffman, P. A., Naval Research Lab., Bellevue, D. C.
Hofmeister, C. A., Penn. Elec. Coil Corp., Pittsburgh, Pa.
Hogan, A. W., Nat'l Advisory Comm. for Aeronautics, Cleveland, O.
Hoss, G. L., National Advisory Committee for Aeronautics, Cleveland Airport, Cleveland, O.
Hull, R. S., National Cash Register Co., Dayton, O.
Hunt, J. E. (Associate re-election), Philadelphia Elec. Co., Philadelphia, Pa.
Jansen, H. R., W. E. & M. Co., East Pittsburgh, Pa.
Jennings, D. R., Gen. Elec. Co., Erie, Pa.
Johnson, E. J., Navy Dept., Cape May, N. J.
Johnson, O., W. E. & M. Co., Columbus, O.
Jost, J. E., York Ice Machinery Corp., York, Pa.
Kafitz, F. H., Naval Ordnance Lab., Navy Yard, Washington, D. C.
Kershner, R. H., W. E. & M. Co., East Pittsburgh, Pa.
Krichbaum, C. E., U. S. Engineer Office, Wright Field, Dayton, O.
Kunst, J. N., Bravo Corp., Wilmington, Del.
Long, F. E., 5503 Montrose Ave., Altoona, Pa.
Luckie, S. B., III, Gen. Elec. Co., Philadelphia, Pa.
Martin, B. V., W. E. & M. Co., East Pittsburgh, Pa.
Matheson, V. A., W. E. & M. Co., East Pittsburgh, Pa.
McCay, W. S., W. E. & M. Co., East Pittsburgh, Pa.
Monroe, C. J., W. E. & M. Co., Baltimore, Md.
Mowry, N. A., Blaw-Knox Co., Pittsburgh, Pa.
Murdock, H. T., Allis-Chalmers Mfg. Co., Norwood, O.
Nagel, W. I., W. E. & M. Co., East Pittsburgh, Pa.
Norrett, E. J., Gen. Elec. Co., Phila., Pa.
O'Bleness, E. L., E. I. du Pont De Nemours & Co., Morgantown, W. Va.
Palmer, B. M., Owens-Corning Fiberglas Corp., Newark, O.
Piper, R. W., Jr., W. E. & M. Co., East Pittsburgh, Pa.
Plotkin, M., Proving Center, Aberdeen Proving Ground, Md.
Podhorzer, E., Army Air Force, Wright Field, Dayton, O.
Sangster, G. E., Potomac Elec. Pr. Co., Washington, D. C.
Sauer, R. L., Gen. Elec. Co., Erie, Pa.
Scheerer, F. J., Monongahela West Penn Public Ser. Co., Fairmont, W. Va.
Schmid, H. J., I-T-E-Circuit Breaker Co., Philadelphia, Pa.
Schnure, F. O., Jr., W. E. & M. Co., East Pittsburgh, Pa.
Schroeder, J. H., Goodyear Aircraft Corp., Akron, O.
Senft, C. E., W. E. & M. Co., East Pittsburgh, Pa.
Slaughter, E. C., Lear Avia, Inc., Piqua, O.
Smith, E. B., W. E. & M. Co., East Pittsburgh, Pa.
Spalding, T. R., Jack & Heintz Inc., Bedford, O.
Spencer, E. G., 2310 Ashmead Place, N. W., Washington, D. C.
Suozzo, J. C., W. E. & M. Co., East Pittsburgh, Pa.
Thomas, G. L., W. E. & M. Co., East Pittsburgh, Pa.
Thompson, A. G., Naval Research Lab., Anacostia Station, Washington, D. C.
Timewell, H. C., British Admiralty Delegation, Washington, D. C.
Trenkle, F. A., W. E. & M. Co., East Pittsburgh, Pa.
Wagner, O. W., W. E. & M. Co., East Pittsburgh, Pa.
Weedman, W. F., Naval Research Lab., Anacostia Station, Washington, D. C.
Welch, G. H. (Associate re-election), W. E. & M. Co., East Pittsburgh, Pa.
White, G. T., U. S. Naval Reserve, Washington, D. C.
Widlar, W. L., Jr., WGAR Broadcasting Co., Cleveland, O.
Wilhite, J. G., Jr., W. E. & M. Co., East Pittsburgh, Pa.

Williams, J. B., Philco Radio & Television Corp., Philadelphia, Pa.
Wood, H. O., Philco Radio Corp., Philadelphia, Pa.
Wuhlberg, A. H., Sylvania Electric Products, Inc., Emporium, Pa.

3. New York City

Adler, L. L., Radioguide Mfg. Co., New York, N. Y.
Andrews, C. J., Federal Tel. & Radio Corp., Newark, N. J.
Bassett, E. D., Chemical Constr. Co., New York, N. Y.
Bentley, W. A., Radio Corp. of Amer., Harrison, N. J.
Biehl, F. A., M. W. Kellogg Co., New York, N. Y.
Bommer, W. F. (Associate re-election), Federal Tel. & Radio Corp., Newark, N. J.
Bradford, C. E., Sperry Gyroscope Co., Brooklyn, N. Y.
Brown, A. C., Sperry Gyroscope Co., Brooklyn, N. Y.
Burger, K. C., Signal Corps, Ground Signal Service, Fort Monmouth, N. J.
Carter, P. D., Gibbs & Hill, Inc., New York, N. Y.
Cockrill, F. J., 140 West St., New York, N. Y.
Collins, G. J., Federal Tel. & Radio Corp., Newark, N. J.
Conklin, L. E., Gair Carton Inc., Piermont, N. Y.
Cosenbo, J. B., Federal Tel. & Radio Corp., Newark, N. J.
Corning, C. T., Federal Tel. & Radio Corp., Newark, N. J.
Dergane, W., Office of War Inform., New York, N. Y.
Dolega, S. J., Con. Edison Co., New York, N. Y.
Edghill, R. A., New York Tel. Co., New York, N. Y.
Edwards, R. S., Sperry Gyroscope Co., Garden City, N. Y.
Elliot, P. J., L. I. Lighting Co., Glenwood Landing, N. Y.
Ellis, B. T., Jr., Federal Tel. & Radio Corp., Newark, N. J.
Feeney, C. J., Western Elec. Co., 120 Bway., New York, N. Y.
Franklin, R. J., The Lummis Co., New York, N. Y.
Froebel, C. A., Standard Oil Dev. Co., Elizabeth, N. J.
Game, K. L., Bell Telephone Lab., New York, N. Y.
Garmaun, J. Jr., Ward Leonard Elec. Co., Mount Vernon, N. Y.
Gerbore, A. E., Bell Telephone Lab., New York, N. Y.
Goodstein, J., Radio Receptor Co., New York, N. Y.
Gray, J. R., Federal Tel. & Radio Corp., Newark, N. J.
Hammond, H. M., Sperry Gyroscope Co., Garden City, N. Y.
Haninger, G. A., Federal Tel. & Radio Corp., Newark, N. J.
Harrington, C. E., Amer. Tel. & Tel. Co., New York, N. Y.
Harrison, W., Wilputte Coke Oven Corp., New York, N. Y.
Hedison, H. D., Jr., Grumman Aircraft Engg. Corp., Bethpage, N. Y.
Johnson, W. C., W. E. & M. Co., Bloomfield, N. J.
Jones, L. F., Federal Tel. & Radio Corp., Newark, N. J.
Kall, A. R., Bell Telephone Lab., New York, N. Y.
Kaufman, L. L., U. S. Navy Dept., Brooklyn, N. Y.
Kerwin, E. A., Newark Signal Corps, Inspection Zone, Newark, N. J.
King, G. W., Sperry Products, Inc., Hoboken, N. J.
Kober, A. A., Wilputte Coke Oven Co., New York, N. Y.
Landeck, J. H., Camp Evans, Belmar, N. J.
Lankford, A. W., Jr., Federal Tel. & Radio Corp., Newark, N. J.
Likon, T. A., Westinghouse Elec. Elev. Co., Jersey City, N. J.
Long, A. S., Federal Tel. & Radio Corp., Newark, N. J.
MacMillan, R., Standard Oil Development, Elizabeth, N. J.
Mandel, M., Federal Tel. & Radio Corp., New York, N. Y.
McAdams, B., Westinghouse Elec. Elev. Co., Jersey City, N. J.
McCusker, R. W., Newark Signal Corps Inspection Zone, Newark, N. J.
Mead, G. G., Gen. Elec. Co., New York, N. Y.
Meinheit, C. E., Sperry Gyroscope Co., Lake Success, N. Y.
Merrill, F. G., Bell Tel. Lab., New York, N. Y.
Mesa, M. F., W. E. & M. Co., Bloomfield, N. J.
Messersmidt, H. L., Bell Tel. Lab., New York, N. Y.
Mezal, J. R. (Associate re-election), Pattengell Elec. Co., Brooklyn, N. Y.
Meyer, R. H., American Gas & Elec. Serv. Corp., New York, N. Y.
Miller, H. M., Federal Tel. & Radio Corp., Newark, N. J.
Mras, W. L., Bell Telephone Lab., New York, N. Y.
Murray, C., Weston Elec. Inst., Newark, N. J.
Neikirk, R. S., Federal Tel. & Radio Corp., Newark, N. J.
O'Connor, J. P., Navy Yard, Brooklyn, N. Y.
Otto, L. C., 32-36—47th Ave., Long Island City, N. Y.
Owen, E. A., Hazeltine Electronics Corp., Little Neck, N. Y.
Phillips, W. R., Jr., Federal Tel. & Radio Corp., Newark, N. J.
Plevritis, G., Curtiss-Wright Corp., Caldwell, N. J.
Pomerene, J. H., Hazeltine Electronics Corp., Little Neck, L. I., N. Y.
Rabito, V. A., W. E. & M. Co., Bloomfield, N. J.
Rogat, S., Heyman Co., New York, N. Y.
Ryan, L. M., Federal Tel. & Radio Corp., Newark, N. J.
Scheerer, W. F., Consol. Edison Co., New York, N. Y.
Shanser, K. S., Carbone Corp., Boonton, N. J.
Simpson, M., Federal Tel. & Radio Lab., New York, N. Y.
Singer, E., Federal Tel. & Radio Lab., New York, N. Y.
Skeris, G. C., Wilputte Coke Oven Corp., New York, N. Y.
Skobel, M., Ft. Monmouth Signal Lab., Little Silver, N. J.
Steinbuhl, R., W. E. & M. Co., Bloomfield, N. J.
Van Fleet, C. D., Standard Oil Development Co., Elizabeth, N. J.
Viney, H. E., Federal Tel. & Radio Lab., New York, N. Y.
Wallenstein, J. P., Federal Tel. & Radio Corp., Newark, N. J.
White, F. W., Bell Telephone Lab., New York, N. Y.
Witzke, L. H., Curtiss Wright Corp., Caldwell, N. J.
Young, K. W. K., Camp Evans Signal Lab., Belmar, Elizabeth, N. J.

4. Southern

Albright, W. G., Virginia Poly. Inst., Blacksburg, Va.
Cormack, L. J., E. D. Badger & Sons Co., Baton Rouge, La.
Drake, L. H., War Dept., Arlington, Va.
Gill, H. W., 2nd Lt., Signal Corps, Headquarters Co. Reporting B. T. W. 503, Signal A. W. Regt., Drew Field, Tampa, Fla.
Haymes, T. W., Jr., Gulf Shipbuilding Corp., Chickasaw, Ala.
Hosmer, J. H., Allis-Chalmers Mfg. Co., Atlanta, Ga.
Knox, J., Univ. of Tenn., Knoxville, Tenn.
Martin, R. A., 2nd Lt., Signal Corps, c/o Postmaster, New Orleans, La.
Mills, M. H., U. S. Army, 1st Sea Search Attack Group (M), Langley Field, Va.
Morrison, A. B., U. S. Army, Johnston, Fla.
Petrou, N. V., 2nd Lt. Signal Corps, U. S. Army, Camp Murphy, Fla.
Sheats, H. W., Jr., U. S. Naval Reserve, Charlotte, N. C.
Stivers, R. M., Tenn. Valley Authority, Chattanooga, Tenn.
Weston, W. H., Jr., Louisville G. & E. Co., Louisville, Ky.

5. Great Lakes

Bradburn, C. T., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Burdick, L. D., The Austin Co., Midland, Mich.
Burk, W. R., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Collett, A. T., Ind. Ser. Corp., Fort Wayne, Ind.
Cooper, J. A., Wabash R. R. Co., Decatur, Ill.
Cremer, G. F., Chicago Signal Corps Inspection Zone, Kokomo, Ind.
Dobbie, C. B., R. C. A. Victor Division, Indianapolis, Ind.
French, A. D., Gen. Elec. Co., Kokomo, Ind.
Gomberg, H. J., Univ. of Michigan, Ann Arbor, Mich.
Kidd, C. S., Jr., Allen Bradley Co., Milwaukee, Wis.
Kunkel, W. R. (Associate re-election), Commonwealth Edison Co., Chicago, Ill.
Lisbakken, R. B., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
London, S., Gen. Elec. Co., Kokomo, Ind.
McKinley, P. H., Allis-Chalmers Mfg. Co., West Allis, Wis.
Messinger, H. P., Ill. Inst. Tech., Chicago, Ill.
Mills, T. L., Gen. Elec. Co., Fort Wayne, Ind.
Monro, C. R., R. C. A. Victor Division, Indianapolis, Ind.
Owren, H. M., Gen. Elec. Co., Decatur, Ind.
Petrucelly, V., Jr., Private, U. S. Army Air Forces, Chanute Field, Ill.
Prak, E. A., Electric Utilities, Chicago, Ill.
Raab, H. P., Jr., R. C. A. Mfg. Co., Indianapolis, Ind.
Raboglatti, E. H., Gen. Elec. Co., Fort Wayne, Ind.
Riggs, R. F., Allis-Chalmers Co., Milwaukee, Wis.
Sauer, J. H., Mid-West Dynamometer & Engg. Co., Chicago, Ill.
Scheibe, E. H., Univ. of Wis., Madison, Wis.
Schmidt, J., Jr., Guardian Elec. Mfg. Co., Chicago, Ill.
Schrot, E. H., Continental Radio & Television Corp., Chicago, Ill.
Smith, E. D. (Associate re-election), Sargent & Lundy, Chicago, Ill.
Soria, R. M., Ill. Inst. Tech., Chicago, Ill.
Stahl, C. R., Gen. Elec. Co., Fort Wayne, Ind.
Valentine, H. W., Jr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Vroman, L., Gen. Elec. Co., Detroit, Mich.
Watkins, J. C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Winglar, W., Allis-Chalmers Mfg. Co., West Allis, Wis.
Wolfe, E., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Yurkanin, R. J., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

6. North Central

Wilson, C. P., 110th Mtn. Signal Co., Camp Hale, Col.

7. South West

Batts, B. F., 2nd Lt. S. C. A. U. S., Kirkwood, Mo.
Cearley, A. G., Curtiss-Wright Airplane Co., St. Louis, Mo.
Dowell, K. P., Texas Technological College, Lubbock.
Dunham, W. H., Jr., Radio Sta. KFBI, Wichita, Kans.
Dunn, C. V., Evans Elec. Constr. Co., Kansas City, Mo.
Franco, G. R., Rural Elec. Admin., St. Louis, Mo.
Parker, E. R., Western Union Tel. Co., Dallas, Tex.
Richardson, T. W. G., Jr., U. S. Naval Reserve, Ward Island, Corpus Christi, Tex.
Smith, F. R., Gulf States Utilities Co., Beaumont, Tex.
Smith, W. J., Rural Electr. Admin., St. Louis, Mo.

8. Pacific

Alexander, D. A., Barrett & Hilp, Hunters Point, Cal.
Allen, F. W., North Amer. Aviation Co., Inglewood, Cal.
Burke, B. R., Douglas Aircraft Co., El Segundo, Cal.
Chamberlin, R. D., Consolidated Aircraft Corp., San Diego, Cal.
Clark, J. S., Bethlehem Steel Co., San Francisco, Cal.
Corcoran, E. G., Douglas Aircraft Co., Los Angeles, Cal.
Felix, H. E., Douglas Aircraft Co., Santa Monica, Cal.
Fowle, J. M., Joshua Hendy Iron Works, Sunnyvale, Cal.
Gauden, G. S., Vega Airplane Co., Burbank, Cal.
Gove, J. T., Douglas Aircraft Co., Los Angeles, Cal.
Hill, C. R., U. S. Army Engr., San Francisco, Cal.
Hudson, G. G., Univ. of Calif., Berkeley, Cal.
Irion, A. D., So. Cal. Edison Co. Ltd., Alhambra, Cal.
Johnson, R. E., McNeil Constr. Co., Las Vegas, Nev.
Lacey, E., Douglas Aircraft Co., Santa Monica, Cal.
Ledbetter, G. W., Douglas Aircraft Co., Santa Monica, Cal.
Lino, J. S., Douglas Aircraft Co., Los Angeles, Cal.
MacDonald, R. Q., Aluminum Co. of America, Torrance, Cal.
Merrill, G. E., Douglas Aircraft Co., Santa Monica, Cal.
Parker, K. L., Douglas Aircraft Co., Santa Monica, Cal.
Porter, N. E., Permanente Metals Corp., Richmond, Cal.
Priedighelt, J. H., Univ. of Calif., Berkeley, Cal.
Rasmussen, D. V., Bethlehem Steel Co., San Francisco, Cal.
Sorem, R. N., Columbia Steel Co., Pittsburg, Cal.
Tesh, K. F., Douglas Aircraft Co., Santa Monica, Cal.

9. North West

Hadley, A. D., Seattle-Tacoma Shipbuilding Corp., Tacoma, Wash.
Huggins, W. H., Oregon State College, Corvallis, Ore.
Johnts, J. A., Jr., Radio Station KIDO, Boise, Idaho.
Lowe, G. P., Boeing Aircraft Co., Seattle, Wash.
Nelson, S. A., Seattle-Tacoma Shipbuilding Corp., Seattle, Wash.
Pritchett, W. S., Oregon State College, Corvallis, Ore.
Smith, E. H., Boeing Aircraft Co., Seattle, Wash.
Wachter, R. V., Aluminum Co. of America, Vancouver, Wash.

10. Canada

Buchanan, K. A., Otis-Fensom Elev. Co., Hamilton, Ont.
Cox, G. M., Research Enterprises Ltd., Leaside, Ont.
Duncan, A. J., B. C. Elec. Ry. Co., Vancouver, B. C.
Gregory, R. R., Railway & Power Engg. Corp., Toronto, Ont.
Johnson, D. G., Research Enterprises Ltd., Leaside, Ont.
Kendall, O. K., National Res. Council, Ottawa, Can.
MacPherson, C. A., Railway & Power Engg. Corp., Toronto, Ont.
Morice, J. H., Jr., Can. Gen. Elec. Co., Peterborough, Ont.
Ort, H. A., Packard Elec. Co., St. Catherine's, Ont.
Quist, J. E., Canadian Gen. Elec. Co., Peterborough, Ont.
Robinson, G. J., Canadian Gen. Elec. Co., Peterborough, Ont., Can.
Rosenthal, A. L., Rogers Majestic Ltd., Toronto, Ont.

Elsewhere

Burgess, G. A., Duncon & District Elec. Supply Co. Ltd., Dunoon, Argyll, Scotland.
Casson, H. V., H. M. S. Odla. c/o G. P. O., London, Eng.
Chapman, W. M., Westinghouse Elec. Co. of Brazil, Rio de Janeiro, Brazil.
de Moschy, C. C., Paramaribo, Dutch Guiana.
Evans, R. R., Jr., Signal Corps, U. S. Army, P. S. O., Quarry Heights, C. Z.
Mandl, L. M., Electricity Meter Mfg. Co., Pty. Ltd., Waterloo, N. S. W., Australia.
Pereira, D. A., Gen. Elec. S. A.-Rio de Janeiro, Brazil, S. A.
Rosenberg, W., Aces Development Co., Manchester, Eng.
Santos, A. C., Westinghouse Elec. International Co., Medellin, Colombia, S. A.
Stocker, J. C., Westinghouse Elec. International Co., Apartado 742, Panama, R. P.

Total to grade of Associate
United States and Canada, 385
Elsewhere, 10

OF CURRENT INTEREST

Ways of Conserving Critical Material to Aid Wartime Electrical Industry

The subcommittee on conservation of materials,* of the AIEE committee on co-operation with war agencies has assembled from information coming to its attention, examples of things that have been and are being done by the electrical industry to conserve critical materials. The subcommittee has obtained this information from many sources and, of course, has had no opportunity to investigate the various measures. Such of the items as have appeared in publications available to the industry as a whole are so credited. Others have been developed at recent meetings at which conservation was the principal theme. Still others have been brought to the attention of the subcommittee informally by engineers well-known in the electrical industry.

Some of these examples, it would seem, may be helpful in suggesting ways of making further savings in critical materials. Taken as a whole the list illustrates the great diversity of the conservation measures which have been and are being employed in the electrical industry to further the war effort.

Notes containing selected examples of this kind were sent to the several AIEE vice-presidents early in November for use in connection with meetings at which conservation of materials was to be the subject for discussion. Thinking such information might be of general interest also to the members of the Institute, the subcommittee has prepared the accompanying summary of the information sent to the vice-presidents and has supplemented it by examples that have come to its attention within recent weeks.

In order to be as helpful as practicable in assembling information along this line, the subcommittee would appreciate receiving from Institute members, information concerning other examples which they believe may be of possible interest to the industry as a whole. Information should be sent to J. W. Campbell, room 1722, 195 Broadway, New York, N. Y.

These conservation measures have been classified as follows:

(*A*) Making the greatest possible use of what we have:
1. Increasing extent of use of existing facilities.
2. Prolonging life.
3. Reuse of recovered materials.

(*B*) Limiting additions to and changes in facilities to those necessary for essential services.

(*C*) Making minimum use of critical materials in necessary extensions:
1. Substitution of less critical materials for more critical materials.
2. Redesign to use less material.
3. Limiting additions to those required for immediate needs only.
4. Standardization.

(*D*) Getting back into circulation materials which can be spared:
1. Clean up and dispose of junk.
2. Reduction of inventories.
3. Taking materials out of working facilities.

* The personnel of the subcommittee on conservation of materials is as follows: H. M. MacDougal, *chairman;* J. W. Campbell; Thomas Spooner; P. L. Alger; R. W. Wilbraham; E. V. Sayles; A. E. Silver; M. S. Oldacre; and O. H. Doan.

Making the Greatest Possible Use of What We Have

INCREASING USE OF EXISTING FACILITIES

Utilizing idle generating capacity by interconnection.

Assisting customers to make maximum use of their present electrical facilities and getting customers to schedule loads in off-peak periods. (*Edison Electric Institute Bulletin, April 1942, page 131.*)

Helping telephone customers to get more use out of their present service and equipment by shifting calls to off-peak hours, relocating telephones, shortening holding time on calls, improving practices of customers' operators and relieving them of extraneous duties. (*Contributed.*)

Loading transformers and voltage regulators to maximum capacity. (*AIEE Transactions, volume 61, 1942, September section, pages 669, 692.*)

Increasing system kilowatt capacity by reduction of generator kilovar requirements and provision of reactive capacity of other points in the system. (*Edison Electric Institute Bulletin, October 1942, page 363; Electrical World, June 27, 1942, page 90; AIEE Transactions, volume 61, 1942, May section, page 249.*)

Increasing loads on circuit breakers and switches by resurfacing contacts with silver alloy. (*Electrical World, October 17, 1942, page 65.*)

Conserving copper in secondary systems and saving transformer capacity by fusing and banking transformers. (*Electric Light and Power, June 1942, page 84.*)

Increasing capacity of transformers by use of supplemental cooling, packaged units, forced cooling, and addition of cooling tubes. (*AIEE technical paper 43-56, AIEE Transactions, volume 62, 1943; Electrical World, June 13, 1942, page 69; October 3, 1942, page 77; October 31, 1942, page 102.*)

Avoiding placing of new cables by increasing loads on existing cables. (*Edison Electric Institute Bulletin, November–December 1942, page 405; AIEE Transactions, volume 61, 1942, March section, page 107.*)

"Borrowing" spare and duplicate equipment for more active duty. (*Contributed.*)

Placing cross connecting terminals at judiciously selected points permits of working existing telephone cables to higher percentage of use. (*Contributed.*)

Meeting needs for submarine cable by having armoring placed on land cable drawn from stock. (*Contributed.*)

Making rearrangements of feeder and distribution plant, which under normal supply conditions are not warranted; raising allowable equipment loading; reducing or eliminating spare capacity; and permitting departure from standards of service. (*Contributed.*)

PROLONGING LIFE

Patching existing machines to avoid replacement. Parts patched include packing journals, vanes of water impellers, gear teeth, stoker crank shafts; valve stems and seats; turbine nozzle partitions; turbine runner. (*Electrical World, June 13, 1942, page 43; June 27, 1942, page 88; July 11, 1942, page 52; Edison Electric Institute Bulletin, February 1942, page 6.*)

Metalizing used to rebuild worn shafts, bearings. (*Society of Automotive Engineers paper, "Metal-Coating of Automotive Parts," H. S. Ingham, John E. Wakefield.*)

Putting stand-by equipment back into service. Example, a 45-year-old water-wheel generator put back into operation after 17 years as stand-by. (*Contributed.*)

Reversing windings on star connected hydrogenerator after fifteen years of service to obtain additional life. (*Electrical World, May 30, 1942, page 84.*)

Restoring worn felt heads on carriers, used in pneumatic tube system, to original diameter by subjecting them to high compression. (*Contributed.*)

Getting more life out of tools by instructing employees in proper care, improving repair practices, keeping rope dry, using tools longer before discarding. (*Mill and Factory, February 1942, pages 75, 168; Power, June 1942, page 79; Purchasing, March 1942, page 58.*)

Restoring cutting edges on reclaimed tools by chromium plating; edges are thus rebuilt and are generally better than unplated tool steel. Files are reclaimed by dipping in acid and giving them a thin chromium plating. (*Contributed.*)

Deferring for the duration, conversion of manual telephone central offices to dial operation, as replacement of existing equipment becomes desirable. (*The Northwestern Bell, December 1942, page 11.*)

Inspecting more frequently critical points of apparatus and equipment, and repairing small defects before they cause failure and serious damage. (*Contributed.*)

Providing instructions for repair of home appliances. (*Electrical World, November 28, 1942, page 96.*)

Leaving wires and cables in service even though, in the long run, it would be more economical to replace them with new cables. (*Contributed.*)

Exercising greater care in installation, operation, and maintenance of vital rubber products—wires, cables, belts, hose, gloves. Avoid exposure to excessive heat, keep free from oil, store in cool dark places, avoid mechanical abuse. Increases life from 10 to 200 per cent. (*Power, June 1942, page 64.*)

Tightening control of normal fire hazards which might cause destruction of stores of irreplaceable supplies and equipment. (*Contributed.*)

REUSE OF RECOVERED MATERIAL

Weatherproof wire is recovered for reuse by sorting and cutting out short bad sections; when braid is too bad for reuse, even though reimpregnated with compound, it is stripped off and wire is reused as bare conductor. (*Salvage and Scrap Material Manual for the Utilities; Industrial Salvage Section, Conservation Division, War Production Board.*)

Improved methods of sorting and storing permit recovery of short lengths of wire used for interconnecting equipment in telephone central offices. (*Telephone Review, December 1942, page 10.*)

Rubber covered wires and cables in communication systems are repaired in place whenever practicable; good sections of wire returned to the shop are spliced together and braid is reimpregnated using newly developed machinery. (*Contributed.*)

Damaged transformers are repaired by installing new parts such as core and coil assemblies. All reusable parts of such transformers are saved for assembly into good transformers. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, pages 3, 9, 12.*)

Lead covered cables removed from plant are reused after being inspected and repaired; duct splices are used to join short lengths of power cables. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, page 15; March 1942, page 19.*)

Practices developed for repairing recovered lightning arrestors, caps replaced, leads replaced or respliced. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, pages 9, 12.*)

Recovered pole line hardware cleaned, straightened, spray galvanized, and painted. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, pages 12, 16; March 1942, page 11. Edison Electric Institute Bulletin, November 1941, page 459.*)

Recovered porcelain insulators cleaned; chipped places revarnished. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, page 12; March 1942, page 11.*)

Street lighting poles and fixtures repaired, broken poles welded, fixtures rebuilt, good parts reclaimed. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, pages 9, 17; March 1942, page 12.*)

Solder is recovered from wiped joints in cables removed from plant; solder drippings saved. Babbitt recovered from worn-out bearings. (*Edison Electric Institute Conference on Reclamation and Salvage, March 1942, pages 11, 14, 21.*)

Obsolete switches converted to modern type using odds and ends of old bus bars. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, page 9.*)

Valves and pipe fittings repaired, rethreaded, reseated, cracks welded, new discs provided. (*Edison Electric Institute Conference on Reclamation and Salvage, February 1942, page 10; March 1942, page 21.*)

Telephone switchboards removed from one location are reused in other localities; are sometimes converted from one type of switchboard to another. (*The Northwestern Bell, December 1942, page 11.*)

Practices and apparatus developed to avoid damaging telephone line wire during removal. After removal, all good sections are carefully selected and are spliced together with rolled or crimped sleeves. (*Contributed.*)

Old style telephone sets held for emergency are being used to avoid current manufacture of new sets. (*Contributed.*)

Old crossarms are used to make secondary racks. (*Electrical World, November 26, 1942, page 88.*)

How Utilities Are Solving Operating Problems Arising Out of the War. A symposium of 142 actual cases. (*Electrical World, May 30, 1942.*)

Industrial Production's Electrical Aids. (*Electrical World, December 12, 1942, page 66.*)

Limiting Facility Additions and Changes to Those Necessary

In addition to the savings that the power and communication companies have been able to effect voluntarily, substantial savings have also been effected as a result of certain WPB orders which, generally, limit construction to that necessary for the war effort except in cases where the necessary facilities are already available.

The WPB orders also provide the utilities with the preference ratings for the purchase of the necessary materials for maintenance repair, operating supplies, and for minor construction jobs, such as permissible service connections.

Minimum Use of Critical Materials in Necessary Extensions

SUBSTITUTION OF LESS CRITICAL MATERIALS

Substitutions for Aluminum

Aluminum alloy castings, aluminum name plates, and cases for electrical instruments replaced by parts fabricated of wood, steel, plastics. (*Contributed.*)

Aluminum in pole insignia, paints, name plates, and bases and housings for apparatus employed in telegraph operations conserved by substitution of more plentiful materials. (*Contributed.*)

With the exception of condenser foil, substitutions have eliminated practically all requirements for aluminum among the telephone companies; plastics replace aluminum alloy castings for housings of "combined" telephone set. (*Contributed.*)

Substitutions for Copper

Copper for nonconductor purposes replaced by steel, malleable iron, terne-plate, brass, bronze, and zinc; problem of protecting steel against corrosion. (*General Electric Review, July 1942, pages 407–14.*)

Bus bars made from steel pipe and structural shapes; comparison of shapes, tests of current capacities, effect of painting and slotting, problem of heat transfer. (*Electrical World, April 18, 1942, pages 67–8; June 27, 1942, pages 67–8; November 28, 1942, page 49.*)

Galvanized steel wire and strand used for power conductors; State Railroad Commission provisions permitting restricted use; instructions prepared covering use. (*Electrical World, June 6, 1942, page 7; July 18, 1942, page 7; September 19, 1942, pages 50–4; November 28, 1942, page 80.*)

Roof-flashings, rain conductors, and water pipe of ferrous metals replacing copper in building construction. (*Contributed.*)

Steel wire replaces copper in exchange telephone service and, where practicable, in toll lines; copper-clad steel used extensively in toll construction and in drop wire. (*Contributed.*)

Copper-clad steel in both the wire form and the more recently available strip form is finding a number of important new applications. For instance, copper-clad steel is replacing copper blades and jaws for certain types of knife switches in the smaller sizes; copper-clad steel used for conductors of cable for general control wiring in electrical manufacture; $^{1}/_{16}$-inch copper-clad steel strand substituted for 2/0 American wire gauge copper conductors on a 115-kv line. (*Contributed.*)

42-inch salt water circulating pump runner made from cast iron instead of bronze. (*Electrical West, November 1942, page 41.*)

Silver replaces copper for bus bars of government-owned plants. (*WPB Release 1957, October 2, 1942.*)

Brass-coated steel replaces brass in lamp bulb bases; nickel-plated iron instead of pure nickel wire, tin content of solder and size of solder tip of lamp bases reduced. (*WPB Release 1316, June 8, 1942.*)

Zinc coated steel screws and nuts substituted for brass hardware for contact screws in ratings up to 30 amperes. (*Contributed.*)

Plated steel has been substituted for brass in the manufacture of inserts used in molded parts. (*Contributed.*)

Substitutions for Steel

Wood substituted for structural steel shapes in substation construction. (*Electrical World, April 18, 1942, page 100; May 30, 1942, page 91. Electrical West, December 1942, page 47. Edison Electric Institute Bulletin, November 1941, pages 459–61.*)

Wood replacing steel in uprights supporting cables, relays, and repeaters, in telephone offices; designed so that wood can be replaced with steel later. (*Contributed.*)

Hardware changed from steel to wood;

examples: pins and pin brackets, braces, guy guards, street and boulevard poles, racks, transformer platforms, anchors, and fixtures. (*Edison Electric Institute Bulletin, November 1941, pages 459–61; February 1942, pages 48, 52.*)

Wood replaces 95 per cent of steel used in telephone booths. (*Contributed.*)

Reinforced concrete replaces structural steel in telephone buildings. (*Contributed.*)

Plywood and transite substituted for sheet steel for fan housings, air ducts, and perforated transite for perforated sheet steel in acoustic ceilings. (*Contributed.*)

Industrial lighting reflectors manufactured of wood fiberboard, laminated-paper plastic, molded cement-asbestos board and asbestos in laminated sheet instead of steel. (*Electrical World, October 31, 1942, page 74.*)

Cast iron or cast steel substituted in some cases for steel drop forgings for crankshafts, connecting rods, and similar parts. (*Contributed.*)

Merit of precast concrete cones instead of steel anchors for overhead electric lines demonstrated by 12 year's, service in western utility. (*Electric Light and Power, December 1942, page 58.*)

Development of national emergency (lean-alloy) steels emphasizing mechanical and physical properties rather than temperature or corrosion resistance conserves vital elements for use where high alloy steels are essential. (*Chemical and Metallurgical Engineering, September 1942, page 90; Metal Progress, October 1942.*)

Wood, instead of steel, used for cable boxes, meter boxes, and for housing protectors and telephones located out-of-doors. (*Contributed.*)

Cement-asbestos, plastics, glass, and concrete encased glass or terra cotta as substitutes for steel and iron in the manufacture of pipe for various uses. (*Chemical and Metallurgical Engineering, September 1942, page 90.*)

Paper laminated with Vinsol resin made into pipe suitable for electrical conduit or for temporary low-pressure piping as a substitute for steel. (*Chemical and Metallurgical Engineering, December 1942, page 104.*)

Substitutions for Tin

Reduction of tin content in babbitts, solders, and metals for hot-dipping connections; silver brazing for heavy joints instead of 100 per cent tin. (*General Electric Review, July 1942.*)

Tin content of wiping solder substantially reduced by substitution of lead and small proportion of antimony; very substantial reductions also made in tin content of resin core solder. (*Contributed.*)

Silicon bronze replaces tin bronze for higher resistance induction motor bars. (*Contributed.*)

Brass flashed lead coating replaces tin coating on conductors of rubber insulated telephone wire. (*Contributed.*)

Addition of 0.06 per cent copper permits power cable manufacturer to eliminate the 2 per cent tin formerly used in cable sheathing. (*Contributed.*)

Glass and fiber have been substituted for tinned-steel containers for holding solvents, oils, and varnishes. (*Contributed*)

Miscellaneous Substitutions

Lead coating replaces galvanizing on many items of pole line hardware; manufacturing equipment formerly used for zinc galvanizing adapted for lead dipping. (*Contributed.*)

Rust-inhibiting primer and paint used in place of galvanizing on certain items of pole line hardware. (*Mechanical Engineering, January 1942, pages 30–1.*)

Plastics replace rubber as insulation for flexible conduit used in planes, tanks, and boats. (*General Electric Review, October 1942, page 595.*)

Paper, varnished fabric, asbestos, and glass replace mica in the manufacture of certain communication and electrical equipment. (*Contributed.*)

Bushings and insulation spacers in communication equipment changed from rubber to wood, fiber, or plastic. (*Contributed.*)

Special silicon iron is being substituted to a considerable extent for nickel iron alloys used for laminations. (*Contributed.*)

Nickel saved by the substitution of high strength carbon steel for nickel-bearing alloy steels in the manufacture of electrical apparatus. (*Contributed.*)

Electrozinc coatings replace cadmium finishes for many applications. (*Contributed.*)

Glass replaces critical metals: glass impellers and plates for centrifugal pumps, glass sole plates for electric irons, glass plumbing for homes and industry. (*Contributed.*)

Copper, tin, and rubber saved by reduction in wire gauges, substitution of tin alloy for pure tin coatings on wires, and reduction of crude rubber content or substitution of synthetic asphalt and wax in insulating compounds. (*Contributed.*)

Glass compositions replace scarce sapphires used as pivot bearings in sensitive electrical instruments. (*Chemical Industries, July 1942, page 38.*)

Storage battery jars made from vitrified ceramic instead of rubber. (*Fortnightly Telephone Engineer, January 1, 1943, page 16.*)

Pentachlorphenol replaces creosote for full length nonpressure treatment of western red cedar poles. (*Electrical World, November 28, 1942, page 94.*)

Concrete, clay, and gypsum products urged as substitutes for lumber to ease shortage. (*WPB release 1930, September 29, 1942.*)

Substitutions in materials and changes in practices covering 56 items representative of electrical utility operation. (*Electrical World, October 17, 1942, page 63.*)

Tin requirements reduced by substitutions in solders, babbitts, and bronzes; steel and iron substituted for aluminum, brass, and bronze; masonite for steel; silver or zinc replacing tin and cadmium plating; carbon for nickel steel; fiber, bakelite, and other plastics used for name plates; bakelite, plastics, and varnished and glass fiber cloth replace shellac, mica, and rubber as insulation; conservation of materials and tools on hand. (*The Canadian Purchaser, December 1942.*)

Wood fiber products substitute for hard rubber, textiles for soft rubber in cords, lower grades and other alloys for grade *A* brass, plywood and steel for aluminum, and wood for steel in telephone plant. (*Contributed.*)

REDESIGN TO USE LESS MATERIAL

Construction of 33-kv line without crossarms or associated pole line hardware. (*Electrical World, May 30, 1942, page 91.*)

Crossarm braces and associated fastenings saved by horizontal *V* type of transmission crossarm construction. (*Electrical World, May 30, 1942, page 92.*)

1,000-kva substation constructed at one-fifth cost and one-fifth space requirements of 600-kva station by simplification of protection devices. (*Electrical World, May 30, 1942, page 91.*)

Design of substations modified to meet wartime necessities: wood substituted for steel; lighter and more flexible structures used without undue sacrifice of safety; duplicate bus arrangements eliminated where practicable; fuses substituted for high side breakers; use of three-phase transformers offers economies compared to three single-phase units. (*AIEE Transactions, volume 61, 1942, March section, pages 117–22.*)

Opportunities for saving of material in building wiring presented through use of *CNX* cable and careful planning of wiring layout. (*Edison Electric Institute Bulletins, November 1941, page 437; April 1942, page 134.*)

Banking secondaries permits use of smaller wire sizes and fewer secondary transformers. (*Electric Light and Power, June 1942, page 84.*)

Load-center distribution system for industrial plants effects savings in critical materials at lower cost. (*AIEE Transactions, volume 61, 1942, May section, page 272.*)

400 tons of copper saved in construction of magnesium plant by careful design of bus bars and ordering feeder cable in exact lengths. (*Electrical West, October 1942, page 48.*)

A supplementary switchboard, consisting of a small table-mounted cabinet has been designed to handle outgoing long distance telephone calls. Requires more operators but saves manufacturing capacity and materials. (*Contributed.*)

Window-type instrument transformers offer savings in copper in manufacture and installation as compared to the bar type. (*Contributed.*)

Greater cooling efficiency through forced circulation of transformer oil permits reduction in size and weight of transformer by one-third to one-half for given capacity with corresponding reduction in materials. (*Westinghouse Engineer, August 1942, page 97.*)

Efforts directed toward reduction of waste material and cutting number of rejections in manufacturing plants yield big dividends. (*WPB Release 1847, September 13, 1942.*)

"Victory joint" saves upward of 60 per cent of tin formerly required for wiped joints. (*New England Telephone and Telegraph Company, "Telephone Topics," March 1942, page 7; Telephone Engineer, April 15, 1942, page 31; Electrical World, August 22, 1942, pages 48–50.*)

Wrapping replaces solder-wiped sleeve joint for cable splices located where they are unlikely to be affected by moisture, as in buildings. (*Contributed.*)

Tin in solder saved by brazing together the wire ends of motors and generators; pressure type connection largely eliminates need for solder in medium-size wire and cable connections to terminals. (*Contributed.*)

Improved design of telephone loading coils ("lumped" impedance) reduces material required by 50 per cent in exchange coils and by 80 per cent in toll coils. (*Contributed.*)

Telephone central office apparatus safely supported on steel members of reduced section. (*Contributed.*)

"Use Next Smaller Rating" proposed as slogan in campaign to save 25 per cent material and labor in motor production. (*Electrical World, August 1, 1942, page 18.*)

High-frequency induction heating of tinned sheet steel after leaving electrolytic plating tanks saves two-thirds of the tin formerly used in dipping process. (*Electrical Engineering, volume 61, December 1942, page 613.*)

"Overmotoring"—its adverse effects on motor production capacity and on the design of the associated transformer and distribution system. (*General Electric Review, October 1942, page 555.*)

Departure from standard design limits saves ten per cent of the copper required for a three-conductor 66-kv underground cable line plus accompanying savings in associated items. (*Contributed.*)

Increasing load ratings of overhead wires, if practicable, where temperature is the controlling factor. (*Contributed.*)

Line wire spliced using single tube compression type sleeves, instead of double tube twisted sleeves, to save copper. (*Contributed.*)

Shellac has been eliminated in certain types of condenser bushings by using a new construction and oil impregnation. (*Contributed.*)

Powder metallurgy offers opportunity for creation of alloys with special properties and cheap and efficient mass production of machine parts not requiring high strength. (*Electrical Engineering, volume 61, September 1942, page 468.*)

Ignitron rectifier units save space and weight over rotary converters of equivalent capacity. (*Electric Light and Power, December 1942, page 44.*)

Shortage of critical materials used in fuse link manufacture emphasizes need to consider measures to reduce or eliminate transformer fuse operation. (*Electrical World, December 12, 1942, page 90.*)

Copper bus saved by paralleling current transformers when station load is increased. (*Electrical World, December 12, 1942, page 98.*)

Interim amendments to National Electrical Code allow savings in material through liberalization of present code standards. (*Supplement to 1940 National Electrical Code, September 1, 1942.*)

Improved arc-welding technique yields stronger weld while using only a fraction of the welding electrode previously required. (*Power, July 1942, page 69.*)

ADDITION OF PLANT FOR IMMEDIATE NEEDS ONLY

Power station extensions limited to facilities required for immediate war necessities, no provision made for growth or non-essential needs. This procedure, in the long run, will make plants cost more but saves materials now. (*Contributed.*)

Telephone cables designed for periods of three years or less instead of more economical periods, effect large savings of copper. (*Contributed.*)

Unit substations, which may be installed quickly and moved quickly to new locations, recommended as means of increasing capacity for war loads economically while offering maximum salvage possibilities after serving their purpose. (*AIEE Transactions, volume 61, 1942, March section, pages 117–22; Electrical World, November 16, 1940, page 60.*)

STANDARDIZATION AND SIMPLIFICATION

At the request of various governmental departments and trade associations the American Standards Association has undertaken standardization of numerous items under the War Standards Procedure. These include:

Protective Lighting for Industrial Properties.
Electrical Indicating Instruments.
Machine Tool Electrical Standards.
Military Radio Equipment and Parts.
Packages for Electronic Tubes.
Fixed Mica-Dielectric Capacitors.
Quality Control.
Replacement Parts for Civilian Radio.
Threading of General Purpose Nuts and Bolts.

In addition, the Simplification Branch of WPB has issued conservation orders simplifying and standardizing some 60 odd items, and orders affecting upward of 150 additional items are in process of preparation (*Business Week, November 28, 1942, page 15.*). Some of the items included are:

Hand Tools.
Scales and Balances.
Batteries, Automotive Storage.
Batteries, Dry Cell.
Cement, Portland.
Seamless Mechanical Tubing.
Soldering Irons, Electric.
Steel Wire Rope.
Structural Steel Shapes.
Switches, Electric.
Incandescent, Fluorescent, and other Electric Discharge Lamps.
Lighting Fixtures, Fluorescent.
Pipe Fittings.
Plywood, Douglas Fir.
Saws, Wood.
Engines, Small Gasoline.
Files and Rasps.
Heat Exchangers.
Instruments, Valves, and Regulators.
Ladders.
Motor Brushes.
Motors, Electric.
Portable Electric Tools.
Pumps, Water.
Taps and Dies.
Valves.
Welding Machines.
Wiring Devices, Electrical.
Shovels, Spades, Scoops, Telegraph Spoons.
Valves.
X-Ray Equipment.
Aluminum, Rods, Sheets, and Tubing.
Auger Bits.
Builders Hardware.
Carbon Steel Plates.
Electrical Control Equipment.
Fittings, Pipe, Steel.

The standards committee of the AIEE is working also on wartime standardization, particularly in producing standard guides to permit maximum use to be made of electrical equipment under various conditions. Further information concerning the work of this committee and a list of the guides that are already available are contained in the article "AIEE Standards Being Revised to Meet Wartime Needs" appearing on pages 114–15 of the March 1943 issue of *Electrical Engineering*.

Getting Unneeded Materials Back Into Circulation

CLEAN UP AND DISPOSE OF JUNK

Changes in methods of handling alloy scrap, old parts, and idle equipment speed manufacture's surplus materials into active use. (*Edison Electric Institute Conference on Reclamation and Salvage, March 16, 1942, page 15; Automotive Industries, October 1942, page 11.*)

Construction gangs salvage scraps of line wire and tie wires found along lines. (*Edison Electric Institute Conference on Reclamation and Salvage, March 16, 1942, page 7.*)

Idle equipment checked for disposition as scrap. (*Edison Electric Institute Conference on Reclamation and Salvage, March 16, 1942, page 7.*)

Committees judge idle apparatus as potential scrap or for sale to venders for reuse. (*Edison Electric Institute Conference on Reclamation and Salvage, February 4, 1942, page 7.*)

Former World War test generator goes to scrap pile. (*Electrical World, December 12, 1942, page 136.*)

Recovered scrap accounts for 7 per cent to 50 per cent of the total new supply of zinc, tin, nickel, copper, and steel. (*WPB Release X-0833, July 13, 1942; Steel Facts, December 1942, page 8.*)

Unused pneumatic tubing scrapped by one utility yields 100,000 pounds of copper. (*Contributed.*)

Iron salvaged from old dump of cast iron borings. (*Automotive and Aviation Industries, October 1942, page 54.*)

Recovery processes applied to ash from refuse and rubbish burned in two process steam boilers and to waste lubricant from wire drawing yield worth-while quantities of metal in electrical manufacturing plant. (*General Electric Review, October 1942, page 592.*)

By pulling out the core alone, copper is salvaged from telephone cables which are so firmly lodged in ducts that the cable cannot be withdrawn intact. (*Contributed.*)

Collecting scrap is a continuing process (*Electric Light and Power, August 1942, page 82.*)

Engineering practices can help to get the maximum value from the nation's metal supply by specifying materials with minimum tendency to produce scrap, selecting fabricating operations that produce least waste in forming, ordering parts in finished form, limiting quality and precision to minimum necessary. (*Metals and Alloys, August 1942, page 3.*)

Survey of lines in service by one utility results in removal of 45,000 pounds of steel-cored aluminum wire for disposal as scrap. (*Edison Electric Institute Sectional Conference, February 4, 1942, page 4.*) Comparable types of surveys by the telephone companies have resulted in recovery of electrolysis drainage wires no longer required, as

well as other items containing critical materials. (*Contributed.*)

Nickel and other critical materials used in alloying steel are "mined" from steel scrap. (*Steel Facts, December 1942, page 8.*)

Slide film, "Get in the Scrap," prepared by Industrial Salvage Section of WPB dramatizes things that may be done by industrial concerns to facilitate collection of scrap. (*For details on film consult regional WPB office.*)

REDUCTION OF INVENTORIES

Utilities release material and equipment in excess of their own immediate needs in order to assist other companies in meeting their essential requirements. (*Contributed.*)

Periodic inventory checks of frequency of use of idle stocks by eastern utility assist in moving material toward useful channels. (*Edison Electric Institute Sectional Conference, February 4, 1942, page 11.*)

Equipment carried for possible reuse checked to determine advisability of putting it into scrap. (*Edison Electric Institute Sectional Conference, March 16, 1942, page 7.*)

Salvage engineer reviews removal work orders and arranges in advance for prompt release of reusable equipment to second-hand market. (*Edison Electric Institute Sectional Conference, March 16, 1942, pages 13–16.*)

Utilities classify inactive cable into groupings which, in addition to showing cable to be junked, furnish an inventory of cable needed for emergency use or suitable for removal elsewhere. (*Electrical World, October 24, 1942, page 4.*)

Transfers of copper from idle and excess inventories enable hundreds of war plants to maintain schedules. (*WPB Release 1826, September 9, 1942.*)

TAKING MATERIALS FROM WORKING PLANT

Multigrounding of primary neutrals and interconnection of arrester grounds with secondary neutrals enable midwest utility to recover considerable amounts of wire. (*Electrical World, May 30, 1942, page 82.*)

Rearrangement of several substations on a 220-kv system releases considerable amounts of equipment to meet expansion at other points. (*Electrical World, August 8, 1942, page 90.*)

Replacement of telephone copper line wire with smaller gauge conductors in cable or by substitution of carrier channels is effecting large net savings in copper. (*Contributed.*)

The addition of a few cable terminals or a short section of cable may result in the release of considerable quantities of telephone drop wire which can be reused. (*Contributed.*)

Circuit breakers removed from existing locations to meet needs of system expansion; those removed chosen by study of the system, its facilities, and historical reasons behind installation of each section. Existing breakers can sometimes be replaced by air-breaks. (*Electric Light and Power, January 1943, page 69; Electrical World, January 9, 1943, page 43.*)

Science Scholarships Awarded by Westinghouse Company

Miss Gloria Lauer, Ames, Iowa, and Raymond Schiff, New Rochelle, N. Y., both high-school seniors, received recently the highest awards of four-year Westinghouse science grand scholarships worth

$2,400 each in the annual science talent search sponsored by Science Service and the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Other Westinghouse science scholarship awards amounting to a total of $6,200 were made to 38 high-school seniors throughout the United States.

Radio Communication Equipment Wanted by Signal Corps

Radio amateurs have been requested to sell their short-wave communication equipment to the Signal Corps, Army Services of Supply. This equipment is needed both for training purposes and operational use, the War Department has announced.

The radio communication equipment needed consists of transmitters, ranging in power from 25 watts to 450 watts and covering various bands in the short-wave range, as well as the corresponding types of receivers and such radio components as capacitors, resistors, and installation material. Especially desired are audio-frequency and radio-frequency signal generators and oscilloscopes, precision a-c and d-c voltmeters, ammeters and milliammeters, and other equipment for testing.

Used equipment will be purchased if it is in perfect operating condition or if it can be restored readily to such condition. The price paid for each item will be set by a Signal Corps inspector. Persons in possession of the desired equipment who wish to sell it for the use of the Army are invited to send a brief description, including the name of the manufacturer and model type, to Captain James C. Short, at the Philadelphia Signal Corps Procurement District, 5000 Wissahickon Avenue, Philadelphia, Pa.

The complete list of the desired equipment follows:

Transmitters—Hallicrafter and Collins.

Receivers—Hallicrafter, National, RME, Hammarlund, and Howard.

Meters—Weston.

Capacitors—mica and paper.

Oscilloscopes—audio signal generators and radio-frequency Signal Generators.

Electrical Engineers Needed by Signal Corps

The United States Army Signal Corps still has a need for electrical engineers as commissioned officers, particularly engineers qualified in the fields of radio and electronics because of education and experience.

While the appointment of officers from civilian life has been considerably reduced under recent policies of the Secretary of War, applications are urgently desired from men qualified as radio engineers and electronic physicists. These occupations, under present policy, have been classified as scarce categories, and men in this group between the ages of 22 and 45 are eligible for commission. For other branches of electrical engineering, men may be commissioned if they have reached the age of 35.

Some of these men may be assigned immediately to Army duties which they are qualified to perform by virtue of their civilian experience. Others may be assigned to special officer training courses and technical training in electronics and high frequency radio, in order to fill vital positions in specialized Signal Corps activities.

Persons interested in commissioned service with the Army, in accordance with the foregoing program, should apply to the local Officer Procurement District office nearest to their homes. They should not apply to the Chief Signal Officer, since the procurement function has been taken over by the Officer Procurement Service.

War Training in Communications Aided by Bell Laboratories

The 22d class of the War Training School conducted by Bell Telephone Laboratories, New York, N. Y., completed its course February 18, 1943, and left for further training or for duty as civilian employees of the United States Army. This school has now trained 1,300 men in the operation of communications developed by Bell Laboratories. Its "faculty" is composed entirely of 36 members of the Bell Laboratories technical staff. So new is the information to be imparted that the "faculty" has already had to write nearly 2,000 pages of textbook material.

The school, which is under the direction of R. K. Honaman (F '36), was organized as the result of a request of the Signal Corps, and the first class began on April 27, 1942.

Instruction now goes on eight hours a day and six days a week, and students from the Navy and other branches of the Army are included. Registration for the school is handled entirely by the armed forces. Applications through the Bell Laboratories cannot be considered.

OTHER SOCIETIES •

Symposium on Dielectrics to Be Held by Electrochemical Society

A symposium on the dielectric problems involved in the development and maintenance of insulating materials is to be held under the auspices of the Electrochemical Society April 9–10, 1943, at Pittsburgh, Pa. This symposium, which AIEE members are invited to attend, will be under the direction of F. M. Clark (A '24), chairman of the committee on dielectrics of the Electrochemical Society and technical assistant engineer, laboratory, General Electric Company, Pittsfield, Mass. The following papers will be presented:

ELECTRICAL PROPERTIES OF POLYVINYL ACETATE. **T. W. Dakin,** Westinghouse Electric and Manufacturing Company

CHEMICAL CHANGES AFFECTING THE STABILITY OF CELLULOSE INSULATION. **F. M. Clark,** General Electric Company

HIGH TITANIA DIELECTRICS. **E. Wainer,** Titanium Alloy Manufacturing Company

PRESSITE, IMPROVED METHOD FOR MOLDING ELECTRICAL PORCELAIN. **K. H. Fischer,** Westinghouse Electric and Manufacturing Company

ALUMINUM ELECTROLYTIC CONDENSERS. **P. Robinson, J. Burnham,** Sprague Specialties Company

CATHODIC CORROSION OF CABLE SHEATHS. **Herman Halperin,** Commonwealth Edison Company

A. A. Potter Receives 1943 Washington Award

Audrey A. Potter, dean of engineering at Purdue University, Lafayette, Ind., and chairman of the National Advisory Committee on Engineering and War Training, has been awarded the Washington Award for 1943 for "distinguished leadership in engineering education and research, and patriotic service in mobilizing technical knowledge for victory in war and peace." The presentation was made on February 24, 1943, at the Union League Club, Chicago, Ill.

The award, established in 1916, is made annually by the Washington Award Commission, which is composed of nine representatives of the Western Society of Engineers and two each of the AIEE, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the American Institute of Mining and Metallurgical Engineers. The recipient must be an engineer "whose work in some special instance or whose services in general have been noteworthy for their merit in promoting the public good."

Future Meetings of Other Societies

American Chemical Society. Spring convention, April 12–16, 1943, Detroit, Mich.

American Society of Mechanical Engineers. Spring meeting, April 26–28, 1943, Davenport, Iowa; semi-annual meeting, June 14–16, 1943, Los Angeles, Calif.

American Society for Testing Materials. Annual meeting, June 28–July 2, 1943, Pittsburgh, Pa.

Association of Iron and Steel Engineers. Spring conference, May 10, 1943, Pittsburgh, Pa.

Electrochemical Society. April 7–10, 1943, Pittsburgh, Pa.

Midwest Power Conference. Annual meeting, April 9–10, 1943, Chicago, Ill.

National Electrical Manufacturers Association. Spring meeting, April 20–23, 1943, Chicago, Ill.

National Fire Protection Association. May 10–14, 1943, Chicago, Ill.

Westinghouse photo

This 45,000-kw, 3,600-rpm turbine generator was installed recently by the Connecticut Light and Power Company; the 50,000-kva generator is hydrogen cooled

Protective Footwear Standards Developed by ASA

The war committee on protective occupational footwear of the American Standards Association has prepared drafts of proposed standards on conductive work shoes for men and electrical hazard shoes for men. These footwear specifications are being formulated with the idea of promoting increased protection for manpower in war industries involving electrical safety hazards. Proposals to develop specifications for women's conductive shoes are being studied by the committee. Recently the American War Standard for Men's Safety-Toe Work Shoes was completed.

Information pertaining to protective footwear standards and proposed standards can be obtained from the American Standards Association, 29 West 39th Street, New York, N. Y.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without letter, the other lettered. Captions should be supplied for all illustrations.

Inventions, Patents, and the Engineer

To the Editor:

The article, "Inventions, Patents, and the Engineer," by W. E. Crawford in the January 1943 issue of *Electrical Engineering*, pages 10–16, should be carefully read and analyzed by every engineer or other person who has any desire to form an opinion as to the merits and demerits of the United States patent system. Fortunately, the special interests of the engineer do not conflict in any way with the interests of the public in this respect. The engineer has, however, a greater interest in the matter than the average citizen because of a closer contact with inventions.

W. E. Crawford is obviously a man who can draw proper conclusion from an extensive experience. It is of the utmost importance that other engineers think as clearly on this and other important questions that are now before us. Engineers are particularly dependent upon the patent system for continued employment, and particularly for the opportunity to do what

they most desire to do, namely, to produce new and improved processes and apparatus. Obviously, if the new things can be duplicated by competitors as fast as they are produced, it is going to be hard to induce anyone to finance their development, and abolishment or further curtailment of the patent system means less employment for engineers and, what is worse, less opportunity for the engineers to use their creative powers. Mere engineering which consists in applying old rules to the production or operation of old things is not much fun, and an engineer who spends his life in merely filling out calculation sheets misses the thrill of seeing something, which he helped to create, operate successfully. A large part of technical education in the United States is directed to fitting engineers to design new things, but few of us, even now, ever get a chance to do much original design work. Much of our time is spent on details of design or revamping of old designs, which involves very little creative thinking.

If the patent system is abolished or rendered ineffective by socialistic changes, not only will the total employment of engineers be reduced, but present designs will be frozen and creative work by engineers greatly reduced. Obviously, if new designs become available to everyone as fast as they are produced, there is not much incentive for anyone to do the engineering and development necessary to produce them. We can admit that the desire for profit is low and ignoble, but the fact remains that it is a force that has produced results up to date, and no one has yet demonstrated to my satisfaction that anything can take its place as an effective driving force.

It is really essential that those who have been taught to think clearly use their heads during the next few years and thus help guide and direct the great mass of our people who cannot do so. The world is groping for a new and better social order, and we should all work for it, but we should try to be sure that it will be better and not just new. We should be equally careful, as Mr. Crawford points out, that we do not follow rule 816 and condemn changes just because they are new.

The question of changes in the patent laws is just one phase of the broader question of what sort of a government we really desire. Absolute freedom is, of course, impractical, although some Indian tribes are able to approximate it closely, thanks to a beneficent government. Most of us give up our freedom for 40 or more hours a week during which we work for and under the direction of a master. We cannot obtain our freedom by hanging the boss, as our serfdom is imposed by our necessity to eat, sleep, raise children, and wear clothes, and our self-imposed necessities, like smoking cigarettes and drinking hard liquor. We accept restraint when it is profitable for us to do so, and industry accepts the restraint of patents for the same reason.

The socialists believe that it would be individually profitable to us to give up more of our freedom to the state. Perhaps this is true, but freedoms lost are hard to regain, and before we surrender any freedom, we had better be sure that we get an adequate price for it. The right to own and to be protected by the state in the ownership of private property is such a freedom. Any right of ownership is merely a right of exclusion. A boy's ownership of a bicycle is merely a right of exclusion, as, if he could find a bicycle he would not need a license to ride it. Whoever owns the bicycle merely has a right to prevent others from riding it, and if bicycles were common property, anyone who could find one could ride it without interference. An inventor has a moral right to his invention, since he created it; that is, he has a moral right to prevent others from using it. We do not, however, recognize this moral right, but grant a rather limited legal right under a patent because we think, quite correctly, that by so granting patents we promote the common good. If, as socialism teaches, private property is a public wrong and we should not be allowed to exclude others from the use of things, of course, patents are wrong. In the final analysis, the decision depends on whether you think democratically or socialistically, whether you believe in individual rights or an all dominant public right. It is, however, a virtue of the American system that such questions are decided by the majority, and if a majority of the people want more socialism, the rest of us must submit. The socialists have made great gains during the last ten years, and this movement to abolish patents or modify the patent and other laws as to private property is purely socialistic.

I agree with Mr. Crawford that the attempts of the socialists to abolish or impair seriously the effectiveness of the patent system are most unwise. I hope I am not too much influenced by the fact that those who propose these changes obviously have had little experience with the system and only a very superficial knowledge of how it operates. Mr. Crawford seems to blame Thurman Arnold for his hostility to the patent system. Thurman Arnold is, however, an Assistant Attorney General of the United States, and whatever his socialistic bias, if he has one, the fact remains that he undoubtedly has been trying sincerely to do his duty. Even if we consider him an advocate of a new social order, which we do not desire, we should still try to assist him as far as it is in our power to understand the facts.

The businessmen and the patent lawyers are at fault in being violently hostile and non-co-operative toward the socialists. If you do not like a man, it is not fair to assume that he cannot have any honest opinions. If those in power have false ideas arising from ignorance of facts, it is the duty of those having knowledge of the facts to cure this ignorance regardless of how little respect they have for the ignoramus.

Mr. Crawford is quite right that the patent system has suffered from being linked up with antitrust matters. There is no real connection. The antitrust laws deal with actions which are in restraint of trade by conspiracy or concerted action. The patent laws relate to rights primarily of individuals, since only an individual can apply for a patent, and no patent can ever be the result of a conspiracy. It is charged that patents are used illegally to further the ends of such conspiracies, which is true, but the remedy is to punish the conspiracy, not to amend the patent laws. Automobiles are used by criminals, but seizing all automobiles, while it may be an effective cure for this situation, is not a good solution.

We are suffering also because the patent lawyers, engineers, and inventors are too much inclined to follow rule 816, cited by Mr. Crawford, as to all improvements in patent procedure. To say that patent law and patent procedure cannot be improved is, obviously, to impute to a system an infallibility not found in anything of human contrivance. Of course, the system can be improved and greatly improved, and perhaps if we started to think about how it could be improved and spent less time abusing those who are seeking to improve it, we would all be better off.

Mr. Crawford speaks as an engineer accustomed to thinking accurately about realities when he says that to him invention merely means something new and useful. If we go back to the fundamental purpose of the patent laws, which is merely to encourage the production of new and useful things, it is hard to see wherein "invention" is at all essential. It is extremely hard to see why one man should be rewarded for producing something by a flash of genius and another refused a reward for something he has produced by long research and the sweat of his mind. If the result is new and useful, the public benefits equally regardless of how it is produced. It has long been my opinion that we could well abandon this archaic idea that invention is anything more than a specialized form of mechanical skill, and I think if the claims of a patent correctly and fairly define the degree of novelty and a reasonable degree of utility due to this novelty is present, the patent should be held valid. I have urged this view on my brethren at the bar, but we have so long dwelt under this fiction of invention that we believe it has some validity. Few engineers of my acquaintance accept it, and perhaps the reason this theory appeals to me is that I made a precarious living as an engineer for a considerable period before I broke down the fence into what I thought was a greener pasture.

What Mr. Crawford says about compulsory licensing is very true. It is extremely hard to conceive of any governmental bureau that could decide what would be a fair royalty. In fact, the hardest problem we patent lawyers have is to fix damages for infringement in which the actual damage to the patentee and the profits of the infringer are susceptible of some proof. If we cannot fix what is a fair compensation to a patentee for use of his invention after this use has occurred, I think it impossible to guess at what would

be a fair compensation before the use occurs. It is true that we arrive at such rates by bargaining when licenses are granted, but the whole theory of collective licensing is based on the theory that bargaining has been ineffective and that the patentee should be forced to grant a license on terms unacceptable to him. Obviously, the patentee is about as badly situated if his patent can be used by anyone on terms fixed by a governmental agency as he would be if it could be used without any compensation. The socialists adhere to the doctrine that there should never be an absolute right to any private property, and their attempts to abolish patents are quite consistent. One valuable by-product of this war, however, is undoubtedly the lesson being taught the American people as to how Government, by the compulsion of Government bureaus, works. A chance remark made by a high official of the Government that, if an inventor does not himself make full use of his invention, he should be forced to allow others to use it, is at the base of this movement for compulsory licensing and is only one phase of the general theory that all private property rights are subject to confiscation if some governmental official thinks it necessary, the price to be paid being fixed by the Government. Such a right of eminent domain, of course, has existed as to land for a long time, and under war regulations it exists as to many other things. Particularly it exists now as to patents, and there is now no need to go to compulsory licensing to further our war effort. The socialists, while they are in power, are trying, however, to set up their new social order so that we shall live under a system set up to win the war after the war is over.

Mr. Crawford deserves the thanks of every citizen of the United States for his very acute analysis of this situation, and particularly because he has given the engineers something to think about. The kind of world your children and my grandchildren will live in depends upon how clearly the American people can think, and those who are trained and paid to think had better work overtime at it.

I think, however, that the time has come for an impartial and thorough survey of the whole patent system, and I have some hopes that the Patent Planning Commission can do some good. I am afraid that it is too big a job for any part-time organization, however well qualified its membership. The President, in my opinion, made a very wise selection in naming the members of the Patent Planning Commission, but I do not think the job can be done without a vast amount of work and without incurring considerable expense, and certainly it cannot be done without help from the engineering societies and business organizations. It is even possible that the Patent Bar could help a little. The Patent Office can, of course, be of great help, but the Patent Office does not have much contact with patents after they are issued, and only a rather narrow contact with industry at any time. There are few evils within the Patent Office, except lack of money and facilities, that the commissioner does not have power to cure. If Congress would give the Patents Planning Commission a substantial appropriation so that it could hire assistants to collect facts and do the necessary paper work, I think our chance of getting any results would be much better.

In any event, I would favor a working patent committee under the chairmanship of Mr. Crawford in the Institute or, better, a joint committee of all the engineering societies. Certainly the engineers should interest themselves actively in regard to any proposed reforms that vitally affect their interests.

FORD W. HARRIS (F '13)

(Senior partner, Harris, Kiech, Foster, and Harris, Los Angeles, Calif.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Hypergeometric and Legendre Functions with Integral Applications to Equations of Potential Theory. By C. Snow. United States Bureau of Standards, Washington, D. C., 1942. 319 pages (photo-offset of long-hand), diagrams, 11 by 9½ inches, paper, $2. (ESL.)

This work has been compiled for workers in applied mathematics and is intermediate between tables of the numerical values of these functions and a treatise on their pure theory. The linear and quadratic transformations and analytic continuations of the ordinary hypergeometric function are derived and written out at length with special space devoted to the associated Legendre functions, and to a smaller extent Heun's generalization of the hypergeometric function. Many applications to potential theory are developed.

Television Standards and Practice. (Selected papers from the Proceedings of the National Television System Committee and its panels.) Edited by D. G. Fink. Mc Graw-Hill Book Company, New York, N. Y., London, England, 1943. 405 pages, illustrations, etc., 9½ by 6 inches, cloth, $5. (ESL).

This volume has been compiled from the National Television System Committee *Proceedings*, on which are based the standards for television broadcasting in use in the United States. The papers chosen for the present book are those that directly underlie the official standards. They comprise a symposium on the engineering problems of the television engineer and the radio industry.

Table of Arc Tan X. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York, as a report of official project 165-2-97-22, mathematical tables project. A. N. Lowan, technical director; conducted under the sponsorship of and for sale by the National Bureau of Standards, Washington, D. C., 1942. 169 pages, tables, 11 by 8 inches, cloth, $2. (ESL).

This table of the inverse tangent is claimed to be the most comprehensive yet published. The angle is given in radians, and the function is calculated to 12 decimals, calculated over the range of x from 0 to 10,000.

Engineering Mechanics. By G. N. Cox. D. Van Nostrand Company, New York, N. Y., 1943. 301 pages, diagrams, etc., 9½ by 6 inches, cloth, $3. (ESL).

Endeavors to co-ordinate the desires of engineering teachers as expressed in the surveys conducted by the Society for the Promotion of Engineering Education. The book is intended for undergraduate students majoring in engineering, and calls for a working knowledge of physics and the calculus.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Patents at Work, a Statement of Policy. Officer of the Alien Property Custodian, Washington, D. C., 1943. 25 pages.

Welding and Brazing Alcoa Aluminum. Aluminum Company of America, Pittsburgh, Pa., 1942. 99 pages, no charge.

A General Outline of Restricted Relativity. By Vladimir Karapetoff. Scripta Mathematica, New York, N. Y., 1943. 18 pages, 35 cents.

A Course in Radio Fundamentals. By George Grammer. American Radio Relay League, Inc., West Hartford, Conn., 1942. 104 pages, 50 cents.

Electric Arc Welding Machine and Electrode Standards. Publication No. 42-81, National Electrical Manufacturers Association, New York, N. Y., 1943. 75 cents.

The American War Standard for Protective Lighting of Industrial Properties. American Standards Association, New York, N. Y., 1942. 50 cents.

After the War—Toward Security. National Resources Planning Board, Washington, D. C., 1942. 61 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the June 1943 Supplement to Electrical Engineering—Transactions Section

Metering Power on the Low-Voltage Side

A. J. PETZINGER
ASSOCIATE AIEE

B. E. LENEHAN
ASSOCIATE AIEE

POWER consumers often are supplied from high-voltage distribution or subtransmission circuits through transformer banks. When such consumers are to be charged on the basis of high-voltage or primary supply, some way of including the transformer losses is desirable without resorting to the difficulties and expense of direct primary-circuit metering.

Where metering is applied on the low-voltage side of the power transformers, errors introduced in the high-voltage input values are due to the losses in the transformers, and are of two kinds:

1. Core losses: These are very closely proportional to the square of the voltage and independent of load. The core losses consist of hysteresis and eddy-current losses in the iron. These losses are also affected by frequency, but the variations in frequency on modern systems are so small that the effect is negligible. Changes in temperature likewise have too small an effect to be considered.

2. Copper losses: These are proportional to the square of the current. Copper losses may be divided into two parts; namely, the ordinary I^2R losses, such as would be caused by resistance R, and the eddy-current losses. The temperature coefficient of the former is positive, while that of the latter is negative. Since the I^2R loss is the larger, the net effect is that losses increase with temperature. A temperature rise of 50 degrees centigrade increases the losses by about ten per cent, whereas the resistance of copper changes by roughly 20 per cent over this range. Actually, the effect of temperature changes can be disregarded in the present discussion, since it is a small percentage of the power being measured. Some of the methods to be given can be made to compensate easily for temperature changes, but this is more of a theoretical advantage than a practical one.

Transformers of the size used in serving consumers from medium-voltage lines may be about 99 per cent efficient at full load, with roughly equal division of the losses, or one-half per cent core loss and one-half per cent copper loss. In some cases, however, the copper loss at full load may be almost twice as high as the core loss.

There are two different metering arrangements in common use:

1. Current transformers on the high side and potential transformers on the low side.
2. All instrument transformers on the low side.

Arrangement 1 will measure the core loss but not the copper loss. Arrangement 2 does not include any transformer losses.

Various[1] methods may be used to include the effect of the transformer losses. Some are:

1. Estimation of losses from the meter readings.
2. Loss or compensating meters may be added to measure voltage squared and current squared, which, by proper calibration, will read core loss and copper loss, respectively.
3. Line-drop compensators may be used to correct for transformer resistance drop and so include copper loss.
4. Dummy loads may be added to instrument transformer secondary windings to correct for core loss.
5. Methods 3 and 4 may be combined, using compensators for copper loss and dummy loads for core loss.
6. Light-load and full-load meter adjustments may be altered to shape the load curve to the reciprocal of the transformer efficiency curve.
7. Methods 3 and 6 may be combined, by using compensators for copper loss and light-load adjustment for core loss.

These methods will be taken up in order for a typical case. The following assumptions are made:

1. The installation is three 200-kva single-phase transformers fed from 13,200 volts.
2. Core loss is 1.1 kw per transformer at rated voltage.
3. Copper loss is 1.9 kw per transformer at rated load.
4. Consumption is 150,000 kilowatt-hours per month. The month is assumed to consist of 730 hours.

From the above information, the core loss at rated voltage is seen to be:

$3 \times 1.1 \times 730 = 2{,}409$ kilowatt-hours

If the average voltage differs from rated voltage, the core loss will be approximately 2,409 × (average voltage ÷ rated voltage)^2.

The copper losses can only be approximated. The 150,000 kilowatt-hours could be 206 kw for 730 hours, or 600 kw for 250 hours, or many other combinations of load and time between these limits. The figure of 600 kw is set as the probable upper limit of the load, since any higher load might damage the transformers.

206 kw for 730 hours, the lowest possible loss for this registration, gives $3 \times 1.9 \times 730 \times (206/600)^2 = 490$ kilowatt-hours

600 kw for 250 hours, the highest probable loss, gives $3 \times 1.9 \times 250 = 1{,}424$ kilowatt-hours

The customer ordinarily would not install an excessively large transformer bank, nor would he dangerously overload it. Consequently, the loss limits are set, the former condition giving a lower loss limit (core loss plus continuous-load copper loss), and the latter giving the upper loss limit.

The various methods will now be discussed in detail.

1. Estimation of Losses From the Meter Readings

The increase in the energy rate to cover losses should be such that the total

Paper 43-34, recommended by the AIEE committees on power transmission and distribution and instruments and measurements for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted November 27, 1942; made available for printing December 22, 1942.

A. J. PETZINGER is a meter engineer, and B. E. LENEHAN a general engineer, both with the meter engineering department of Westinghouse Electric and Manufacturing Company, Newark, N. J.

energy per month, multiplied by the increase in rate, will equal the total transformer losses over the month multiplied by the usual energy rate. Expressing this as an equation, let

E = energy metered on secondary winding side per month
L = transformer losses per month
R = usual energy rate
ΔR = rate increase

Then

$$\Delta R \times E = L \times R$$

or

$$\Delta R = R \times L/E$$

The percentage increase is evidently L/E which in most cases will be perhaps two per cent as a maximum. Two per cent would be too great at full load, but this compensates for the fact that no energy is being registered at no load, although core loss is still being supplied. The approximation is quite close, as will be seen.

The demand rate should be increased by about one per cent to cover losses at full load (expected demand).

The previous reasoning also makes it plain that discounts may be reduced by the same percentages in order to compensate for the losses; namely, two per cent for energy and one per cent for demand. The estimation below shows how this will work out.

The losses might also be estimated and billed separately at the usual rate.

The estimation in any event would be as follows:

Energy metered = 150,000 kilowatt-hours

Core loss (one-half per cent of transformer rating for 730 hours) is $730 \times 1 \times 3 = 2{,}190$ kilowatt-hours

Copper loss (assume one-half per cent of kilowatt-hours) = 750 kilowatt-hours

Estimated total losses = 2,940 kilowatt-hours

Total energy billed = 152,940 kilowatt-hours

As previously mentioned, there are two limiting conditions:

(*a*). A steady load all month which gives minimum losses.

In this case, the steady load which would deliver the given energy in one month would be $(150{,}000/730) = 206$ kw.

Copper losses would be 490 kilowatt-hours, as calculated previously. Total losses would be 2,680 kilowatt-hours. Total energy supplied would be 152,680 kilowatt-hours.

(*b*). Rated load on for a length of time which delivers the given energy, and no load the remainder of the time.

Thus, 600 kw for 250 hours would give 150,000 kilowatt-hours. The copper losses under these conditions would be 1,424 kilowatt-hours as calculated previously. Total losses would be 3,614 kilowatt-hours, and total energy supplied 153,614 kilowatt-hours.

The estimate is 2,940 kilowatt-hours, whereas the average of the two limiting cases is 3,147 kilowatt-hours. The billing based on the estimation would be within 0.15 per cent of the billing based on the average of the two limiting conditions. Actually, this error is less than those encountered in meter calibration.

The total losses are seen to be just about two per cent of the measured power in either case, which is the justification for the two per cent figure used above.

Even the limiting conditions above give errors of only 0.2 per cent and 0.45 per cent, and these conditions are very improbable. For case *b* (maximum losses), the estimate would be within 674 kilowatt-hours of the actual losses. At 1.5 cent per kilowatt-hour, this would mean a loss of revenue of $10 a month or $120 a year. A metering outfit for use on the high side would cost over $1,000. Interest, taxes, and depreciation would take most of the revenue collected, showing little justification for the use of a metering outfit on this size of load.

Another billing method, not quite so simple as the first given but slightly more accurate, is to add a fixed number of kilowatt-hours, plus a percentage of the energy registered. The fixed number of kilowatt-hours would equal the core loss as previously estimated. The percentage of registered energy would be (copper loss/registered energy) also as previously estimated. This method is obviously the same as estimating the losses and billing at the usual rate.

Also, in general, it is true, that, the higher the registration for a given transformer rating, the more accurate the estimate can be made.

2. Loss or Compensating Meters

Since core loss varies as the square of the voltage, a voltage-squared hour meter consisting of one element for each phase of the transformer will register the core loss if the correct multiplier is used. Similarly, copper loss may be measured by a current-squared meter with the correct multiplier. The error in loss measurement can be reduced to a very small amount, but accurate transformer data are required, and these are not always available or obtainable. Transformer data can be estimated, but design variations are such that the error may be as much as 0.3 per cent of the total power, and the accuracy is not much better than the estimating methods given. When the data are accurately known, the errors generally will be no greater than those

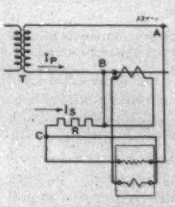


Figure 1 (left). Line-drop compensator—single-phase circuit

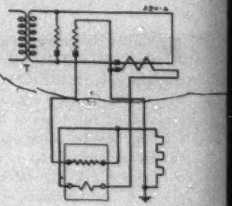


Figure 2 (right). Line-drop compensator—single-phase circuit with alternative connections

involved in metering directly on the high-voltage side and, as will be seen later, may be less.

Compensating meters may be individual current-squared and voltage-squared hour meters, or they may be combined in one meter. Although three elements of each type theoretically would be required, the accuracy is almost as good using one voltage and two current elements.[2] If the load is normally well balanced, one current element is sufficient.

Loss meters also may be used to form the basis for an estimating method. That is, a compensating meter may be installed for a representative period of time, and the losses compared to the registration of the watt-hour meter during that period. This may be used then as a basis for changing the rate. For example, if the losses were 1.75 per cent of the registration during this period, the energy rate evidently should be increased, or the discount reduced, by 1.75 per cent. Loss meters of the current-squared type only would be sufficient in cases where the voltage is known fairly accurately. Most installations probably will fall into this category. A five per cent change in voltage will change core loss by about ten per cent. However, core loss will normally be about one per cent of the registration, so that the net error would be only about 0.1 per cent, if the average voltage differed by five per cent from that estimated.

3. Line-Drop Compensator

Impedances may be used in the secondary windings of current transformers to produce a drop equivalent to that of the transformer bank. This drop may be added to the secondary potential transformer voltage to make a sum proportional to the primary voltage. Since a reactance drop would be at right angles to the current, the added voltage from a reactance-drop compensator would produce no registration on a watt-hour meter. Therefore, only resistance compensation is needed in power metering.

The type of transformer bank determines the number of compensators required; two for open delta, three for star or delta.

Figure 1 illustrates the principle of the line-drop compensator. The current transformer circulates the current I_s in the direction indicated, while I_p proportional to it flows in the main circuit. The voltage between B and A must be increased by the resistance drop in the transformer T to obtain the equivalent high-side voltage. The resistor R is adjusted so that the secondary current produces a drop equivalent to the transformer drop. It is seen that I_p and I_s both flow toward B, so that the polarity is such as to add the voltage drop.

Another way of looking at this is to say that voltage BA would normally be applied to the potential coil, B being at higher potential than A when the current flow is as indicated. The point C, however, is at higher potential than B by the amount of the resistance drop in R. Therefore, if the potential coil is connected from C to A, the potential across it will be greater than BA by the drop in R. The drop in R, in turn, is equivalent to the drop in T, so that the equivalent of the high-side voltage is applied to the meter.

Figure 2 shows the same method, rearranged to permit grounding of instrument transformer secondary windings. The difference from Figure 1 is in the order in which the transformer secondary

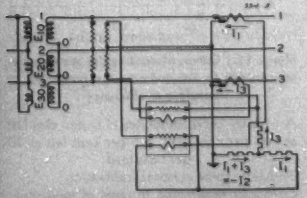


Figure 3. Line-drop compensator used in three-phase three-wire circuit

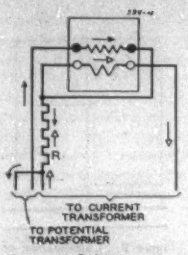


Figure 4. Polarity requirements for line-drop compensators

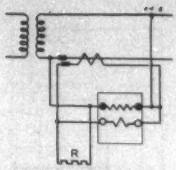


Figure 5. Connection of dummy loads to measure core loss

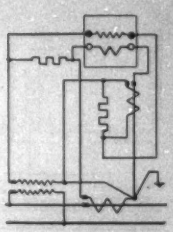


Figure 6. Combination of line-drop compensator with dummy loads using an additional current transformer, single-phase circuit

compensating resistor and meter coil are connected in series.

In Figure 2 the current flows through the compensator and then through the meter. The potential coil is connected across DF. The voltage DE, which normally is applied to the meter, is increased by the drop EF and the total DF, applied to the coil. E is at a lower potential than D, and the drop in EF places F at a still lower potential than E.

Figure 1 is the clearest for single-phase, whereas Figure 2 is simpler in a three-phase circuit, in which a third resistor is needed to compensate for the third phase current as shown in Figure 3.

Note that although only two elements are used, the drops in the three transformers are taken care of by the wye-connected compensator. In Figure 3 the voltage E_{12}, for example, $=E_{10}+E_{02}=E_{10}-E_{20}$. The drops which are added vectorially to this voltage before applying it to the potential coil are the ones caused by the currents I_1 and $-I_2$. ($I_1+I_3=-I_2$.) The addition of these drops gives the equivalent high-side voltages E_{10} and $-E_{20}$, which equals E_{12}.

Although the transformers are shown connected delta-wye, the secondary of course, could be delta-connected, and the meter and compensator connections would not be changed.

The polarity of the connections on a line-drop compensating scheme is important. To add a voltage to correct for IR drop, a drop $-IR$ is needed. This is obtained by connecting the voltage leads so that the currents of the voltage and current circuits are opposite in the compensator (see Figure 4).

Sometimes the wiring may be used to provide the resistance required. For example, with one-half per cent drop, or 0.6 volt on 120-volt basis, the value of R would be about 0.12 ohm at five amperes or say 75 feet of number 12 American wire gauge wire. Where common return wires are used for both current and voltage, a compensating effect occurs. With the usual connection, it results in low readings, since the currents of the voltage and current circuits are in the same direction. When properly connected, however, compensation may be obtained this way without other equipment.

4. Dummy Loads

Dummy loads may be used to correct for core loss. The saturation curve of the core is not a straight line, with the result that the correction will be slightly low on higher than normal voltage, and slightly high on lower than normal voltage.

Figure 5 shows core-loss compensation by means of a dummy load (the resistance R), which allows a current to circulate through the current coil in such a direction as to add the core loss. The value of R usually will be around 5,000 ohms. The saturation curve could be approximated by an iron-cored impedance Z, but adjustment difficulties make this impractical.

5. Line-Drop Compensators and Dummy Loads Combined

Methods 3 and 4 may be combined to correct for copper loss and core loss, but it will be found that the voltage and current connections required are not consistent with each other if both the transformers are to be grounded.

Four alternatives exist:

(a). Use additional current transformers to reverse the current for the resistor compensating for copper loss (Figure 6).

(b). Use additional voltage transformers to reverse the voltage for the resistor compensating for core loss (Figure 7).

(c). Add an extra current winding on the meter to provide the equivalent of b (Figure 8).

(d). Use grounds on only the current transformer secondary windings. The voltage

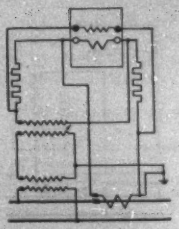


Figure 7. Combination of line-drop compensator with dummy loads using an additional potential transformer, single-phase circuit

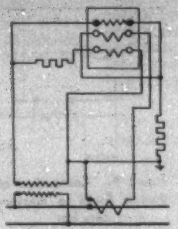


Figure 8. Combination of line-drop compensator with dummy loads using an additional series winding, single-phase circuit

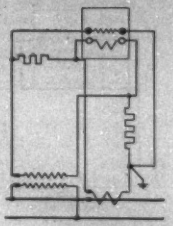


Figure 9. Combination of line-drop compensator with dummy loads, grounding the potential transformer through the current circuit, single-phase circuit

transformer secondary windings will then be grounded through the current circuit[3] (Figure 9).

6. Meter Adjustments

This method consists of setting the meter about five per cent fast at ten per cent load, one per cent fast at full load, and two per cent fast on 50 per cent power factor. Since the effect of the adjustments practically will offset the transformer losses, the over-all result will be quite close over the ranges of load normally encountered.

From the transformer efficiency curve, the full-load and light-load settings can be determined. In the example shown in Figure 11, these values are found to be 1.5 per cent at 100 per cent load and 5.5 per cent at 10 per cent load. In this case, the resultant curve is fairly good over the whole range. If the transformers are under no load a fairly large portion of the time, it may be advisable to use a meter without anticreep holes or slots in the disk so that it will creep with voltage only applied.

If the disk has no irregularities of any sort, the core loss will be measured with very good accuracy, since the light-load adjustment provides a torque which varies as the square of the voltage, as does the core loss.

Note, however, that the same uniformity of the disk would be required of a meter on the high side, if the core loss were to be measured during periods of no load. Therefore, metering on the high side may be less accurate than some of the methods described here.

The method of determining the desired curve is as follows:

Take the reciprocal of the transformer efficiency curve. This is the curve which the watt-hour-meter registration should match. The standard watt-hour-meter curves are then changed by three adjustments. Full-load adjustment changes all points equally. Lagging adjustment changes all points at any given power factor (say 50 per cent) equally, and intermediate power factors are affected almost proportionally. For example, calibrating 100 per cent load to 101 per cent at unity power factor and 102 per cent at 50 per cent lagging power factor would cause all loads at unity power factor to register one per cent faster than the standard curve. All loads at 50 per cent power factor would register two per cent faster than the standard curve for 50 per cent power factor. At 75 per cent lagging power factor the change would be about 1.5 per cent.

The light-load adjuster supplies a torque independent of load, and therefore the effect on registration varies inversely with the speed. A change of five per cent at ten per cent load would change 50 per cent load by one per cent. Note that 50 per cent power factor will be affected twice as much on a percentage basis as unity power factor at the same current.

By means of these adjustments, the inverse of the transformer efficiency curve usually may be approximated rather closely. In this method, as well as any of the others, the transformer data are helpful in increasing the accuracy. If they are not obtainable, an average characteristic must be assumed.

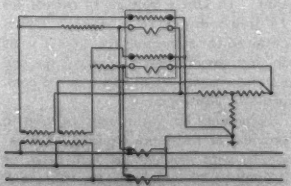


Figure 10. Combination of line-drop compensator with dummy loads, grounding the potential transformer through the current circuit, three-phase circuit

7. Combination of Meter Adjustment and Line-Drop Compensators

Line-drop compensators may be used for copper-loss compensation, and fast light-load adjustment for core-loss compensation. This would be more accurate on unbalanced loads, such as arc furnaces, than method 6, although the advantage is not great.

Reactive Power Measurements

The foregoing applies to power measurement. However, the same methods may be applied to the measurement of reactive power.

The errors introduced are, in general, the same as those involved in power measurement as previously discussed.

The reactive power losses again may be divided into two classes:

1. Excitation losses (corresponding to core loss)—dependent on voltage, but varying much more rapidly than the square.

2. Leakage reactance loss (corresponding to copper loss)—proportional to the square of the current.

Transformers of the type in question will have reactive power losses ranging from two per cent to ten per cent, depending on the transformer design.

The methods which were used for power metering may also be used to include reactive losses. The following points, however, should be noted.

When using line-drop compensators,

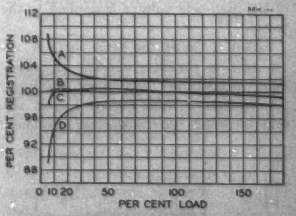


Figure 11. Curves illustrating the use of meter adjustments to approximate the reciprocal of transformer efficiency

A—Meter curve calibrated 1.5 per cent fast at 100 per cent load, 5.5 per cent fast at 10 per cent load

B—Meter curve at normal calibration

C—Meter registration in terms of transformer input

D—Transformer efficiency curve

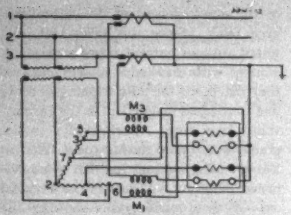


Figure 12. Line-drop compensation used on three-phase reactive meter circuit

reactance only is needed, for the same reason that resistance only is required to measure conductor loss. That is, a resistance drop added to the potential of the reactive meter would produce no rotation. Note, however, that when the reactive meter consists of a watt-hour meter and phase-shifting transformer, the above statements apply only when the compensation is applied on the primary side of the phase-shifting transformer. On the secondary side, resistance compensation could be used, but difficulties in making the proper connections made this undesirable. The best method is probably that shown in Figure 12 which used mutual inductors. This allows more freedom in making connections, since the two windings are not tied together.

It will be observed that the current transformer in line 1 feeds current through mutual inductance N_1 which is in the potential circuit 6–7. This voltage lags 3–2 by 90 degrees and is applied to the element in which the current from the transformer in line 3 is used. The connections of the other inductance are similar.

The use of dummy loads to measure kilovar-hour excitation loss gives somewhat less accuracy than the use of dummy loads for core loss.

If compensating meters of the voltage-squared and current-squared type are used to measure power losses, no additional equipment is necessary to measure reactive power losses. Multiplying the readings of these meters by the correct factors will give the reactive power losses.

Reactive power measurements are subject to errors, because the magnetizing current varies widely with fluctuations in voltage. For this reason, the most accurate method is the use of compensating meters of the voltage-squared type. The kilovar-hours can then be computed from the readings obtained. This method probably is justified only on transformers with high magnetizing current. If the reactive power measurement is used only to determine demand, the errors in any method will be rather small.

Summary

The foregoing will make it plain that several methods of including transformer losses in the billing are available. Both estimating and measuring methods may be used with reasonable accuracy. There is no best method for all installations. Each must be considered individually. The most desirable method is determined by the various factors involved in each installation. These factors will include expense, customer relations, commission requirements, and importance of maintaining laboratory routine, to mention a few of the more important.

Appendix

The fact that the line-drop compensation shown in Figure 3 is correct is proved as follows:

In any delta transformer bank with balanced impedances (Figure 13)

$$\begin{aligned} I_1 &= I_b - I_c \\ I_2 &= I_c - I_a \\ I_3 &= I_a - I_b \end{aligned} \qquad (1)$$

(Since the impedances are balanced)

$$I_a + I_b + I_c = 0 \qquad (2)$$

From equation 1 we find

$$I_1^2 + I_2^2 + I_3^2 = 2(I_a^2 + I_b^2 + I_c^2) - 2(I_a I_b + I_b I_c + I_c I_a) \qquad (3)$$

The actual copper loss $= (I_a^2 + I_b^2 + I_c^2)R$

where R is the a-c resistance of each phase of the transformer. In the meter (see Figure 3) the element with current I_1 has a voltage $(I_1 - I_2)R_c$ added to its potential coil, and similarly the element with current I_2 has a voltage $(I_2 - I_3)R_c$ added to its potential coil, so the loss measured,

$$P = I_1(I_1 - I_2)R_c + I_2(I_2 - I_3)R_c$$

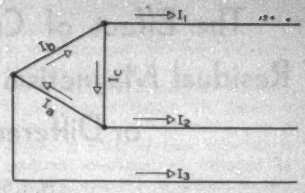


Figure 13. Line and phase currents of the secondary winding of a delta transformer bank

where R_c is the resistance of each leg of the compensator.

Combining terms

$$P = [I_1^2 + I_2^2 - I_2(I_1 + I_2)]R_c$$
$$= (I_1^2 + I_2^2 + I_3^2)R_c \text{ since } (I_1 + I_2) = -I_3$$

Using equation 3

$$P = [2(I_a^2 + I_b^2 + I_c^2) - 2(I_a I_b + I_b I_c + I_c I_a)]R_c$$

Now we add and subtract

$$(I_a^2 + I_b^2 + I_c^2)R_c$$

which gives

$$P = [3(I_a^2 + I_b^2 + I_c^2) - 2(I_a I_b + I_b I_c + I_c I_a) - (I_a^2 + I_b^2 + I_c^2)]R_c \qquad (4)$$

However

$$(I_a + I_b + I_c)^2 = (I_a^2 + I_b^2 + I_c^2) + 2(I_a I_b + I_b I_c + I_c I_a)$$

From equation 2 this equals 0 so the last two terms in equation 4 drop out. The measured loss is therefore

$$3R_c(I_a^2 + I_b^2 + I_c^2)$$

If

$$R_c = (R/3)$$

the measured loss will therefore equal the actual loss

$$R(I_a^2 + I_b^2 + I_c^2)$$

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The Effect of Current-Transformer Residual Magnetism on Balanced-Current or Differential Relays

H. T. SEELEY
ASSOCIATE AIEE

Synopsis: High-speed current-balance relaying has been subject to occasional false tripping that has not been explained satisfactorily. Field and factory tests now show that this is probably due to differences in residual fluxes in the current-transformer cores. The limiting value of these fluxes can be calculated approximately, and they can be measured with portable instruments connected to the secondary winding. They may cause a deficiency in secondary current, especially during the first half-cycle of fault current, which will cause current-balance or differential-overcurrent relays to operate falsely. This false operation can be avoided by the addition of a short inherent or external time delay with relays having a high dropout, or by the use of special current transformers.

BALANCED-CURRENT relaying has been favored widely in system protection, because, in principle, its complete lack of sensitivity to faults outside the protected line makes time delays unnecessary and avoids all problems of co-ordination with the settings of relays further from the source.

Experience with induction-disk relays applied in this form of protection was entirely satisfactory until requirements of system stability or of uninterrupted operation of industrial motors caused a demand for reduction in the fault duration even below the minimum of a few cycles obtained with such relays. High-speed current-balance relays operating in less than a half-cycle were then applied and experience with them also has been satisfactory, generally. However, there has been a very small percentage of false operations resulting in the tripping of a breaker on a sound line, and, if the fault causing this tripping is on the only other line between the two terminals, such false operation naturally causes loss of the tie or interruption of supply. The purpose of this paper is to report an investigation which has shown the probable cause of most, if not all, of the false operations not otherwise accounted for and provided against.

The clew that provided the basis for the investigation was obtained from tests made by G. S. Whitlow, then of the General Electric Company, and C. E. Asbury of the Illinois–Iowa Power Company. They were conducting primary tests with a low-voltage source to determine the reason for one of the false operations mentioned above and found that the only way to cause false tripping with equal primary currents was to reverse the direction of current through the primary winding of one current transformer with respect to the other. The sudden first application of current after a reversal would usually result in operation of one or the other element of the current-balance relay. Since this relay had been tested without current transformers previously with suddenly applied current, they diagnosed the false tripping as being due to residual magnetism in the current-transformer cores. Fortunately, oscillograms were taken during these tests, so the offending element had left some evidence. Figure 1 is a tracing from a typical one of those oscillograms showing the currents which caused false tripping by providing insufficient restraint. The traces show the two secondary currents, and, since the primary conductors of the two current transformers were in series, it is obvious that the deficiency of secondary current in one of the current transformers in the first half-cycle was due to some phenomenon within the current transformer. This phenomenon has been analyzed and will be described briefly at the outset as a basis for an understanding of the test methods and test results described later.

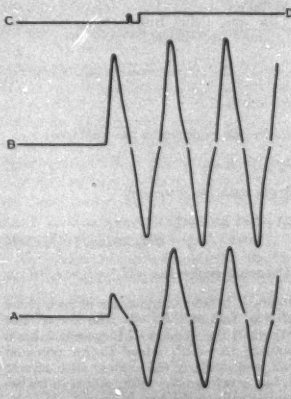

Figure 1. Oscillogram from field tests, showing difference between secondary currents of two similar 38-turn current transformers with similar burdens and 2,540 amperes primary current

2,540/38 = 67
A—Secondary current of current transformer with residual flux
B—Secondary current of current transformer with less (or opposite) residual flux
C—Relay contacts open
D—Relay contacts closed

Hypothesis to Explain the Observed Phenomenon

The following hypothesis appears to be in accordance with the results of the field tests and the factory tests:

1. A significant amount of residual flux is left in the core of only one of the two current transformers which supply one balanced-current relay.

2. This residual flux remains in the current-transformer core practically undiminished unless the circuit is loaded, in which case it is decreased gradually but not usually removed entirely.

3. A subsequent fault beyond (or near) the end of the pair of protected lines with both lines in service will draw equal (or nearly equal) currents through the primary windings of the pair of current transformers as shown in Figure 2. The direction of primary current during the first half-cycle is random and may be such as to require an increase in current-transformer core flux in the same direction as the existing residual flux.

4. The sum of these fluxes is likely to exceed saturation value, in which case there will be a deficiency of secondary current from this current transformer equal to the magnetizing current necessary to produce enough flux to generate the voltage required for the actual secondary current.

5. This deficiency of secondary current will be smaller, possibly even negligible, in the other current transformer because of its lack of residual flux.

6. The greater secondary current from the current transformer without residual flux may operate the balanced-current relay in one direction.

7. Since the location of residual flux (in one

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H. T. Seeley is in the switchgear relay engineering department, General Electric Company, Philadelphia, Pa.

current transformer or the other) is unrelated to the location of the subsequent fault, and the currents are practically equal except for the transient error, an element may operate falsely for an external fault; or an element on the sound one of a pair of lines may operate for a fault in the other line, near its further end.

With the preceding brief outline to show the relation between the various ideas involved, we can profitably cover the first two of the points in more detail.

1. The residual flux may be left by a half-cycle impulse such as a fault current cleared by an expulsion gap or a fuse, or such as a power-frequency current following a lightning arrester discharge; or by a fault current cleared after an odd number of half-cycles; or by a fault current that is offset because it started in an inductive circuit near the zero point of the voltage wave; or by a power-transformer magnetizing-inrush current which is offset because of the presence of residual flux in the power-transformer core prior to its energization. Residual flux may be left in only one of the pair of current transformers because the primary conductor of its mate is out of circuit at the time of the transient; or because the fault causing the transient was on the primary circuit of one current transformer and so near by that the currents in the two current transformers were greatly different in magnitude.

In earlier days of the industry it was considered a serious offense to open-circuit a current-transformer secondary winding partly because of the resulting high voltage, but also because of the danger of magnetizing the core. It is now known that any of the conditions previously mentioned can run the flux density in the current-transformer core up to saturation value if the primary current or secondary burden is high enough, or with smaller currents or burdens if the transient is applied twice or a few times with the same direction of initial half-cycle; and therefore the residual flux introduced by unavoidable circumstances may be practically as great as the value formerly supposed to result only from careless testing or faulty wiring or devices.

2. The fact that normal operation fails to remove the residual flux completely is in accordance with the known characteristics of permanent magnet materials, which differ from transformer iron only in degree even though the degree is extreme. If a large magnetizing force is applied to either of these materials it produces saturation, as indicated in Figure 4, and, if it is reduced to zero without reversal, a residual flux is left, often of just as great a percentage of its own saturation value for high-quality annealed iron as for high-quality permanent magnet steel; the main difference between these steels is in the coercive force necessary to bring the flux to zero.

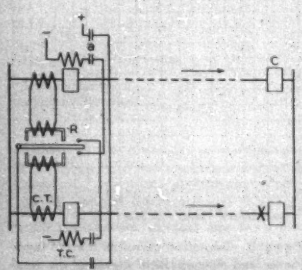
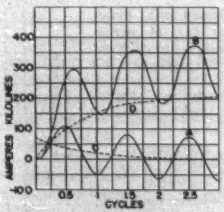


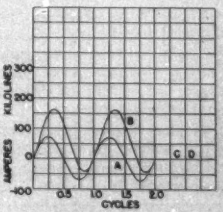
Figure 2. Schematic connections for balanced-current relaying of two parallel lines, showing equal currents in the two lines for a fault at the end of one of them (length of arrows indicates current magnitude)

a = Auxiliary switch, closed when C is closed
C = Circuit breaker
CT = Current transformer
R = Current-balance relay
TC = Trip coil
X = Fault



(a). Wave started at 90+ $(\tan^{-1}X/R)$ degrees after instant of zero voltage, where *X* and *R* constitute the impedance limiting the current in the primary circuit; this gives a fully offset wave

Secondary turns = 38
Core area = 6.4 square inches
Frequency = 60 cycles per second
Time constant = 0.013 second
A—Secondary current
B—Required flux density
C—D-c component of *A*
D—Component of *B* caused by *C*



(b). Wave started at $(\tan^{-1}X/R)$ degrees after instant of zero voltage; this gives a symmetrical wave

Figure 3. Secondary currents in burden of 0.77+*j*1.06 ohms, and current-transformer-core flux densities required for these currents

Figure 3a shows a fully offset primary-current wave and the corresponding wave of required flux applying to the current transformer and burden used in the error-current tests. This fully offset wave requires more flux than any other current of the same symmetrical value having a smaller degree of offset. The fluxes required for larger or smaller currents are in direct proportion to the current. Figure 3b shows a symmetrical current wave and the corresponding wave of required flux; this symmetrical wave requires less flux than any other current of equal magnitude with this burden. A purely reactive burden of the same total impedance would require a flux wave of the same amplitude, but this flux wave would be symmetrical, and therefore its peak value would be much less. A reduction in secondary resistance may be even more beneficial with an offset wave, because it decreases the unidirectional component of flux caused by the d-c component of current. These flux waves were calculated from the formula

$$\phi = \frac{10^8}{N}\left(R\int_0^t i_p dt + Li_p\right) \qquad (1)$$

Then, if a pulsating or alternating magnetomotive force is imposed, and this magnetomotive force is small compared with the coercive force of the particular material, the operation will stabilize on what is known in permanent-magnet theory as a minor loop, and this loop will be far removed from the zero axis of flux, one end coinciding with the residual-flux trace of the high-density hysteresis loop unless the small alternating magnetomotive force has been reduced from the maximum value attained since saturation. A phenomenon of this sort is characteristic of current-transformer operation at normal loads, because they require only a small flux density and therefore a fairly small magnetomotive force even when displaced from the zero axis of flux. Figure 4 is a sketch of half of the usual major loop *B* resulting from the application of fault current, within it a minor loop *C* resulting from the subsequent application of full load current, and also a smaller minor loop *D* obtained by finally reducing the load current to half rated value; these minor loops are

not test results, but are intended only to convey an understanding of the phenomenon.

Outline of Tests

In an effort to duplicate in the factory the false operation obtained in field test, a series of tests was laid out using a similar burden on current transformers of nearly the same size as those used in the field tests, and with secondary turns chosen to require the same flux density as those current transformers for the same secondary current. A method was devised, and checked, for measuring residual flux without decreasing it greatly quantity in the investigation. Also, it was felt that a method of residual-flux measurement using only portable meters and readily obtainable test power would be useful for field work. Another requirement for the investigation at hand was that the method should not decrease the residual flux very much in the process of measurement, since it was desired to produce a residual flux by applying a typical transient, measure this flux, and then use the flux after measurement to cause an error current which could be measured, or checked for its effect on a relay.

For the above reasons a method was devised which consists of applying to the

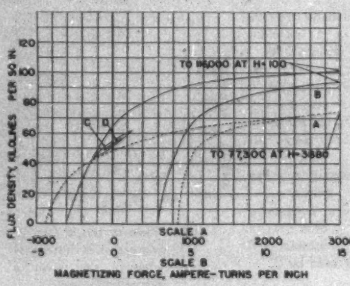


Figure 4 (left). Residual flux of permanent-magnet steel and ingot iron

A=Alnico permanent-magnet steel
B=Ingot iron, hydrogen-annealed
C=Minor loop in ingot iron
D=Minor minor loop in ingot iron

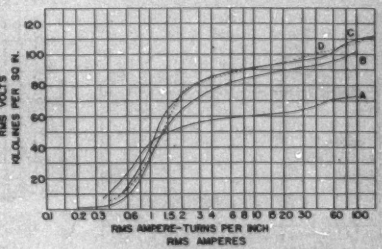


Figure 5. Saturation curves of current transformer and magnetization curves of the steel

A—A-c saturation curve, 38 secondary turns
B—D-c magnetization curve, 38 secondary turns
C—A-c magnetization curve of steel, calculated from *A*
D—A-c magnetization curve of steel, design data

and measurements were made by this method of the residual flux left by various transients. Tests were made to determine whether the passage of time or of rated current would cause a decrease in the residual flux left in the core. Oscillograms were taken showing primary current, secondary current, and error current with and without residual flux, and others were taken showing primary and secondary current and relay operation with and nonoperation without residual flux.

Table I lists for reference the dimensions and other pertinent data on the current transformers and burden used in the tests.

Nondestructive Test for Residual Flux

It was apparent at the outset that ballistic measurements of residual flux left by typical primary-current transients would not be feasible, since the zero-flux reference point would be obliterated by the transient; and also because splitting the core, even though the joint surfaces were ground, would introduce an unavoidable gap which would decrease the residual that was the most important secondary winding a very small measured 60-cycle magnetizing current and measuring the voltage necessary to circulate this current through the winding; this method will hereinafter be described as the impedance method of residual-flux measurement. By trial of this method it was found that the voltage decreased as the residual flux increased, and the relation between the volts per turn per square inch and the residual-flux density was determined experimentally by the use of a portable flux meter (which is equivalent to a ballistic galvanometer). This relation is shown in Figure 6 for a magneto-

Table I. Characteristics of Current Transformers and Burden Used in Test

Core material	2.75 per cent silicon steel
Core construction	Spiral strip
Core treatment	Annealed after welding ends
Core diameters	$8^3/_4$ inches outside, $6^3/_4$ inches inside
Core height	$7^3/_4$ inches
Active core area	6.4 square inches (space factor 0.88)
Mean flux path	24.4 inches
Windings	Two, of 38 turns each, 0.12 ohm each
Burden at 5 *A*	$0.65+j1.06=1.16$ ohms
Burden at 50 *A*	0.72 ohm
Size constant (2)	491
Saturation curves	Figure 5

motive force of 0.258 root-mean-square ampere turns per inch of core length. The induced voltage is very sensitive to magnetomotive-force magnitude, as can be seen from the fact that a force half as great gave no measurable voltage, and so the curve should not be used to determine residual flux with any other value of magnetomotive force impressed. The voltages were measured by means of a rectifier type of voltmeter because of the relatively low impedance of the dynamometer type.

A determination of the decrease caused in residual flux by this magnetomotive force was made by leaving the flux meter connected during the instant when the measuring force was first applied; Figure 6 shows also this relation.

Measured Values of Residual Flux

Measurements were made by the ballistic method to determine the relation between the flux density produced by application of a given value of magnetomotive force and the residual-flux density remaining after removal of this force. This test was made at various values of flux density up to saturation, and the results are shown in Figure 6. The results as plotted are a characteristic of the grade of iron in the transformer and not merely a characteristic of this particular size of transformer. It will be noted that the residual flux is 60 to 85 per cent of the maximum flux immediately preceding.

This information enables one to assign a maximum value to the residual-flux density which will be left in a current-transformer core by a given transient, if

Table II. Measured Flux Density Left in Current-Transformer Core by Various Transients

Trial	Oscillogram	* Wave	Amperes	Cycles	Flux Density, Kilolines Per Square Inch: Before Test	Added by Test (From Figure 3)	Residual (From Figure 6)	Residual Measured
1	8A	S	.50	7.0	Small	40	.24	.30
2		S	.50	6.5	0	162	.75	.53
3		S	.50	6.5	45	162	.75	.58
4		S	.50	6.5	50	162	.75	.60
5	8B	S	.20	5.5	0	65	.56	.32
6		S	.20	5.5	23	65	.74	.56
7		S	.20	5.5	48	65	.75	.67
8		S	.20	5.5	50	65	.75	.70
9		O	.50	6.0	0	380	.75	.35
10	8C	O	.50	6.0	27	380	.75	.67
11		O	.50	6.0	60	380	.75	.67
12	8D	O	.50	1/2	0	295	.75	.65

*S = Symmetrical.
O = Completely Offset.

he knows the initial density, core dimensions, turns, and voltage required by the burden for this particular transient; it is necessary only to determine from the usual transformer relation the peak flux density corresponding to the required voltage, add it to the initial density, and read from the curve the maximum residual-flux density that can be left in the core.

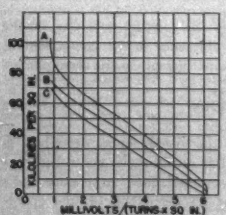
Measurements were made by the impedance method to determine the residual-flux density left by various transients such as are likely to be caused by lightning discharges or other insulation failure. To permit direct comparison of the results with various types of transients, the tests were all made at the same steady-state value of secondary current, approximately 50 amperes, with a burden of 1.16 ohms. The results are given in Table II. The measured values are usually less than the ones predicted from Figure 6, partly because the maximum density is less than the calculated value by reason of saturation of the burden and partly because the d-c component of error current partially restores the core flux to symmetry if the transient continues more than one cycle, thus further reducing the maximum density reached during the last half-cycle.

A test was made showing how residual flux can accumulate as a result of successive transients which happen to have the same polarity of initial half-cycle. The results are the second, third, and fourth trials listed in Table II; also the fifth to eighth, and the ninth to eleventh.

Permanence of Residual Flux

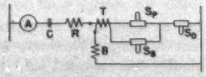
The core was magnetized and the residual-flux density, measured by the impedance method, was found to be 75,000 lines per square inch. The core was left undisturbed for about 40 hours, after which a check measurement gave the same readings.

A current of five amperes at 60 cycles was then applied to the primary, requiring a secondary voltage of 5.8 and a calculated peak-to-peak flux density of 18,000 and was left flowing for about 24 hours, after which another check measurement showed that the residual-flux density decreased to 23,000. Lower currents would cause smaller decreases, but no investigation was made of this relation, or of the relation between time and residual flux, at five amperes load.



(Left) A = Maximum flux density during last half-cycle before applying test current
B = Residual flux density before applying test current
C = Residual flux density after applying test current

Figure 6. Relation between induced voltage and previous flux values, at 0.258 ampere turns per inch of core length, 60 cycles



A = Ammeter
B = Burden
C = Synchronous switch
R = Reactor with air gap
S_D, S_P, S_S = Shunts with oscillograph elements; difference current, primary current, and secondary current respectively
T = Current transformer under test

Figure 7. Circuit for oscillographic measurement of error current

Oscillograms of Error Current

The concept of error current or exciting current in a current transformer has sometimes seemed elusive, and it was thought that the nature of the phenomenon being investigated would be made clearer if we could get a direct measurement of this current in a form which would permit visualizing its relation to the primary and secondary currents.

An oscillogram provides the best means for visualizing an electrical quantity, especially a transient one, and so the apparatus was arranged to provide a portion of the circuit where error current could be measured directly. Referring to Figure 7, the primary and secondary windings, having an equal number of turns, were connected in series with oscillograph shunts. From the junction of these two shunts a third one was connected to receive the difference between the primary and secondary current; this difference is the error current, when the turn ratio is 1/1. When the current transformer transforms perfectly, there is no voltage drop across the error-current shunt and no current in it, but, when the ratio breaks down, the error current flows in this shunt. This method is subject to a slight inaccuracy, because, when this shunt carries current, there is a voltage drop across its terminals which helps the secondary induced-voltage drive current through the burden impedance, so that the error current obtained is somewhat less than it would be if the secondary circuit were closed directly on itself, and therefore the results are slightly optimistic. The maximum instantaneous drop across this shunt was 13 volts as compared with an instantaneous value (calculated from the oscillogram) at the same instant, of 23 volts induced in the secondary winding, but the inaccuracy of results seemed slight enough to be tolerated for the sake of obtaining a direct record of error current.

Typical oscillograms obtained with this circuit are reproduced in Figure 8. Oscillograms (*A*) and (*B*) show the difference in behavior, with symmetrical waves of primary current, depending on the absence or presence of residual flux; (*C*) and (*D*) show the corresponding comparison with fully offset waves. The residual-flux measurements show how the succeeding cycles of fault current in (*C*) removed a large part of the flux put in by the first half-cycle, which was similar to (*E*).

Effect on Relay

The final test of the hypothesis was an experiment to determine whether the increase in error current, already shown to result from the presence of residual flux in the core, would permit picking up a relay which would be restrained successfully in the absence of the residual core flux.

The burden for this test consisted of a

current-balance relay plus enough artificial burden to bring the total external burden up to $0.57+j0.82=1.01$ ohms. Including the internal resistance, the total resistance was 0.69 ohm, giving a size constant of 550.

In the course of this experiment it was found that

1. The normal transient error current without residual flux was sufficient to permit operation of a current-balance relay energized from the primary and secondary currents of the same 1/1 current transformer.

2. The difference between the transient error currents of similar current transformers without residual flux and with equal primary currents but with different burdens was sufficient to permit operation of a relay balancing the two secondary currents.

After these difficulties were overcome, it was found that

3. With similar current transformers, no residual flux, equal burdens, and equal primary currents, the relay would not operate.

4. With similar current transformers, equal burdens, and equal primary currents, but with residual flux in only one current transformer, the relay would operate.

The oscillograms of tests 3 and 4 are reproduced in Figure 9.

Effect on Generator Differential Protection

This phenomenon need have no effect on generator-differential protection using only two sets of current transformers, since they can be demagnetized before being put in service if it is suspected that they are magnetized, and their subsequent histories are identical. It should be considered, however if three sets of current transformers are used, as is sometimes necessary with double-bus arrangements or with station-auxiliary transformers tapped off between the generator and its circuit breaker. The reason is that the currents during a given fault, and therefore the residual fluxes resulting from it, are necessarily unequal in the three sets of current transformers; and a subsequent fault involving the opposite one of the two sets of current transformers in the line side of the generator winding will encounter different residual fluxes in the two sets involved this time and may cause false operation of the differential protection if its delay is inadequate.

Effect on Bus Differential Protection

This phenomenon affects differential-overcurrent relays used for bus protection just as much as it affects balanced-current relaying. However, as has previously been pointed out,[1] this effect is unimportant in comparison with core saturation caused by the d-c component of an offset current, and so it need be considered only in marginal cases, if at all.

Effect on Instantaneous Residual-Current Relays

Residual-current relays are often considered advantageous, because their settings are independent of load current. In some cases, such as a single line terminating in an ungrounded winding of a machine or a transformer bank, no selectivity is required, and therefore instantaneous relays have been used. Such relays are liable to false operation because of error currents resulting from different residual fluxes in the current transformers of different phases. Such inequality of residual fluxes in the event of a phase-to-phase fault can result from a previous ground fault, or from a previous phase-to-phase fault involving a different pair of phases. Such false operation of an instantaneous ground-overcurrent relay has been recorded in service, although it has not been determined whether the major cause was the residual core flux or the inherent difference in d-c component of the transient currents in the three phases.

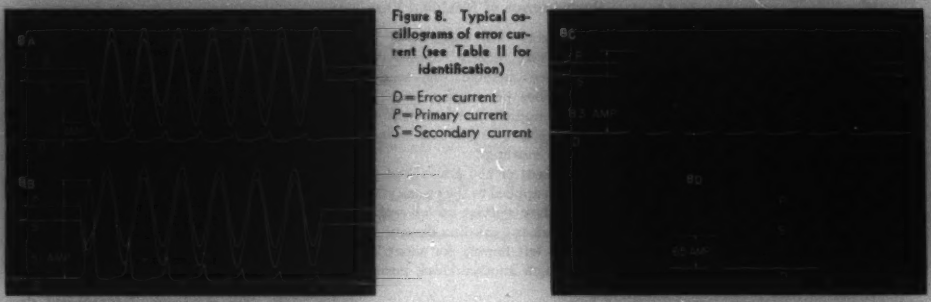


Figure 8. Typical oscillograms of error current (see Table II for identification)

D = Error current
P = Primary current
S = Secondary current

Conclusions

While the phenomenon described is reproducible at will under controlled conditions, reported field experience indicates that the percentage of false operations that might be traced to it is small, and undoubtedly there are many locations where these improbable operations can be tolerated. However, some locations require the greatest obtainable reliability,

Figure 9. Oscillograms of relay operation with, and nonoperation without, residual flux

9*A* = With residual flux in only one current transformer
9*B* = Without residual flux in either current transformer
P = Primary current
R = Secondary current in restraining coil
C = Current in contact circuit

Effect of Radio Frequencies of a Power System on Radio-Receiving Systems

C. V. AGGERS
ASSOCIATE AIEE

W. E. PAKALA
ASSOCIATE AIEE

W. A. STICKEL
NONMEMBER AIEE

IN the last few years considerable work has been done, in this country by the Joint Co-ordination Committee on Radio Reception of Edison Electric Institute, National Electrical Manufacturers' Association, and Radio Manufacturers' Association, and in Canada by the Department of Transport, to develop radio-noise measuring circuits and instruments.[1,2] The methods[3] of measuring radio noise and the instruments have reached the point in their development where the data obtained with these standard instruments can be correlated and the radio-influence characteristics of electric apparatus and power systems can be determined.

Radio co-ordination of electric apparatus is conveniently divided into two classes—low-voltage and high-voltage. The low-voltage class consists of apparatus used below 1,200 volts and frequently operated by and on the premises of the radio listener. Considerable co-ordination work has been done on this class of apparatus, and values of radio-influence voltage have been established for certain appliances and small motors. The high-voltage class includes apparatus used in the generation, transmission, and distribution of electric power. The problem of co-ordination of radio reception with this class of apparatus is more complex than it is for the low-voltage equipment and has not been completed.

This paper is concerned with high-voltage apparatus and describes tests and method for calculating the over-all effects on radio reception resulting from the radio-frequency voltages produced incidentally by power apparatus. The calculations depend upon a number of factors for some of which the range and probable values have not been determined. One of these factors for which information is required is the coupling factor of antenna to power lines and is defined as the ratio of field intensity at the radio listener's antenna to the field intensity under or near the transmission line. To determine this coupling factor, field tests were made at radio frequencies in a city receiving power from 25-kv transmission lines and 4-kv distribution circuits. A radio-frequency generator was connected to the 25-kv bus at the substation, and field-intensity measurements were made near the power lines and at 29 receiver antennas located at various distances from the 25-kv lines. The coupling factors to the nearest power circuit and to the 25-kv line were thus obtained for all the antennas tested.

Various other data useful in radio co-ordination were obtained. These include equivalent effective height of outdoor antennas used by radio listeners, types of grounds and distances from antenna to high-voltage and low-voltage lines.

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C. V. AGGERS is manager of the X-Ray Division, Westinghouse Electric and Manufacturing Company, Baltimore, Md. W. E. PAKALA is liaison engineer, central engineering laboratories and standards department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. W. A. STICKEL is with the West Penn Power Company, Pittsburgh, Pa.

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Radio Co-ordination—High-Voltage Apparatus

In order to obtain a basis for evaluating the various factors in the radio co-ordination problem, it is necessary to provide a method of calculating the effect on radio reception of the radio-frequency voltages which may be generated by line and station apparatus. It can be shown that the following factors must be considered:

(*a*). Broadcast-station field intensity in microvolts per meter.

(*b*). Signal to noise ratio acceptable to radio listener.

(*c*). Ratio of interference field intensity at antenna to value at high-voltage line.

(*d*). Ratio of radio-influence voltage on line to field intensity under or near the line.

(*e*). Ratio of radio-influence voltage measured with standard laboratory-test circuit to voltage which will appear on line when apparatus is connected.

(*f*). Effect of service conditions.

Discussion of Co-ordination Factors

(*a*). Broadcast station field intensities depend on the locality and can be measured with the standard radio-noise meter. The magnitudes of the field intensities available as a function of the percentage of radio listeners is beyond the scope of this paper.

(*b*). The signal to noise ratio acceptable to radio listeners is probably in the range of 30 to 40 decibels. What the ratio should be depends on the type of radio program and the environment of the listener. Some background noise can be tolerated in most cases if the program is quite understandable without undue concentration provoked by the background noise.

(*c*). The coupling of antenna to high-voltage line determines the effect on the radio receiver of radio-frequency fields under or near the power circuits. Because the coupling factor varies over a wide range, it is necessary to use distribution curves for the data and to use values of the factor which are significant for the case or area considered. The tests described in this paper were outlined and made with the purpose of obtaining more information on this antenna-power-line coupling factor.

and for them it seems necessary to seek a means of avoiding false tripping.

One means, but not a very practical one, is to demagnetize both sets of current transformers after each external fault when only one circuit is in service, and after each internal fault.

Another means is to use only relays with sufficient delay to permit the error current to reduce the residual flux and thus prevent completion of their false operation. This delay may be inherent, or it may be incorporated in an external definite time relay if the balanced-current relay has a dropout high enough to permit it to reset when the secondary currents again approach equality.

In cases where high-speed relaying is essential, the best solution lies in the use of current transformers with small or large air gaps in the cores.[2] Ironless couplers[3] could be used, but would provide a smaller output and require a more sensitive relay.

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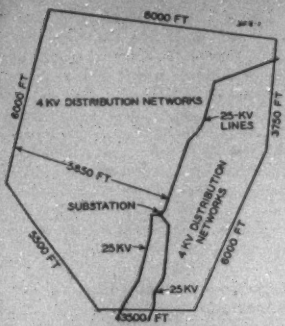

Figure 1. Outline of city in which radio coordination tests were made

Twenty-five-kilovolt lines to substation shown—four-kilovolt distribution spreads over area along with necessary street lighting, d-c feeder and telephone circuits

Twenty-five-kilovolt lines, four-kilovolt distribution, telephone on same poles along lines. D-c feeders also on two lower line sections

Table I. Antenna Characteristics

Type	Length (Feet)	Height (Feet)	Ground	Equivalent Effective Height (Meters)	Feet to Nearest High-Voltage Line	Feet to Low-Voltage Line	Coupling Ratio**
T	42x18	30	Rod	3.6	105	20	0.067
L	50	23	Gas pipe	3	50	12	0.3
L	30	14	Water pipe	0.4	45	21	0.58
L	40	21	Water pipe	3.0	114	10	0.5
L	75	28	Rod	5.0	63	8	0.45
Doublet	25x25	22	Water pipe	1.0	80	24	0.44
L	50	26	Rod	3.6	10	0.16	1.11
L	84	15	*	1.35	60	27	0.72
L	46	22		5.2	66		0.43
L	87	11	Water pipe	3.9	72	25	0.9
Doublets	30-30-12-12	25		0.78	130	8	0.18
L	60	18		13.9	78	25	0.6
L	100	28		1.0	66	20	0.8
Doublet	45x20	33		1.8	24	51	2.5
L	27	35	Water pipe	1.11	150	72	0.8
L	48	15	Water pipe	3.56	30	20	1.0
L	60	22	Water pipe	4.4	84	1	0.053
L	66	22	Water pipe	1.15	75	40	1.1
L	48	20	Water pipe	1.2	85	30	1.4
L	48	20	Water pipe	0.24	52	9	1.71
L (attic)			Water pipe	1.4	108	Home wiring	2.75
L	88	30		0.835	45	10	2.74
Doublet	51x20	39	Water pipe	3.86	75	19	0.21
L indoors					75	Home wiring	1.52
L	36	15	Rod		51	1	0.8
L	66	25	Water pipe	2.66	129	34	0.225
L					110	20	1.0
L					75		1.06
Loop					40		1.00
Averages	53 for *L*'s	22.3		2.83	73	20.7	0.93

* Where no ground was available, measurements were made by using neutral wire of 110-volt circuit as ground connection.

** This is ratio of field intensity at the antenna to the field intensity 30 feet from the nearest high-voltage line.

(*d*). This factor varies with the line height. Values from 55 to 90, average of 70, were measured 30 feet from the line, and under the line wires the values averaged only six per cent lower. In these cases there are 25-kv, 4-kv, and street-light circuits on the same poles, and the field under the line does not decrease with distance from the line so rapidly as it does with single-circuit lines.

(*e*). It is necessary to consider the effect of loading on radio-interference generators. Most generators connected to high-voltage circuits have several times the impedance (600 ohms) used in the standard high-voltage test circuit to load the apparatus. Because of the relatively high internal impedance the radio-frequency voltage which will exist when the apparatus is put in service on a transmission line is directly proportioned to the line impedance. For a line without reflections the load will be one-half the characteristic impedance which varies from 370 to 630 ohms, with an average of 494 ohms as obtained from measurements on several lines made at carrier-current and broadcast frequencies. The average is 494 ohms giving a value of 600/247 = 2.42 for (*e*).

(*f*). The effect of service conditions is not known. Electric apparatus is usually operated near its rating, and no large changes in the radio noise level will occur if ratings are not exceeded. In some cases the location, mounting, and proximity to ungrounded or grounded metal may be such as to change appreciably the electric field in the apparatus and outside of it in such a manner as to change the radio noise level.

The above factors can be expressed in the form of an equation:

$$RIV = \frac{ade}{bcf} \qquad (1)$$

where *RIV* is the radio-influence voltage referred to the standard high-voltage test circuit

If we use 31.6 (30 decibels) for *b*, 70 for

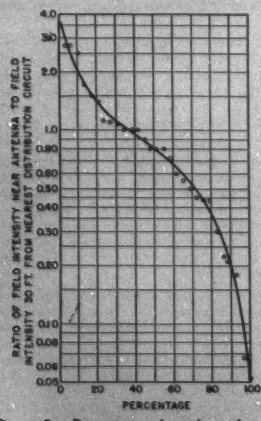

Figure 2. Percentage of total number of antennas tested with ratio (coupling factor) greater than ordinate

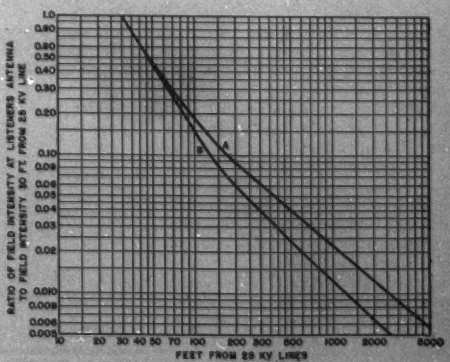

Figure 3. Coupling from high-voltage line to antenna as a function of distance from the line

(*A*). With distribution circuits over the area

(*B*). With no distribution circuits—all transmission through space

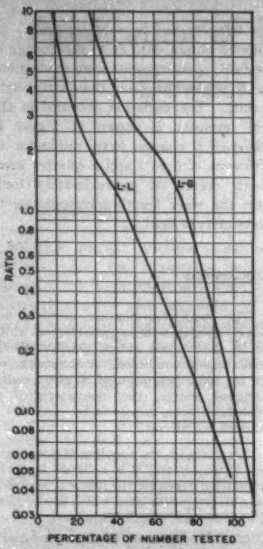

Figure 4. Ratio of line-to-line and line-to-ground voltages on 110-volt circuit to field intensity 30 feet from nearest high-voltage line

d, 2.42 for e, and 1 for f—all of which are reasonable values—and change nomenclature for broadcast field intensity from a to E, equation 1 may be written

$$RIV = \frac{5.36E}{c} \text{microvolts} \qquad (2)$$

In this equation the factor c was considered as one requiring field investigation in order that numerical values of RIV for satisfactory radio reception could be obtained. Field tests were made therefore in an area as shown by Figure 1. This area has 16,000 people with 4-kv distribution, street-light circuits, street-railway network, and 25-kv lines located as shown.

Test Procedure

A slowly keyed signal of one frequency (980,000 cycles) was applied by means of capacitors to one phase of the 25-kv line at the substation. The location of this substation and 25-kv lines relative to the area inhabited by radio listeners is shown in Figure 1. The signal was of such a magnitude that it could be received, without interference, anywhere in the test region and along all transmission lines including the 132-kv lines feeding the 132-kv to 25-kv substation which is several miles from the test area.

Two standard[2] radio-noise meters and a standard signal generator were used as the measuring equipment. Test locations, that is, listeners' antennas, were selected at random along the 25-kv lines and at points several thousand feet and on both sides of the 25-kv lines. At each listener's antenna, the following 980-kilocycle (test signal) measurements or records were made:

1. Field intensity directly under and 30 feet from 25-kv or distribution lines whichever was nearest. (Thirty feet has been tentatively considered as a standard distance. In most cases it is not necessary to leave the roadway to take readings.)

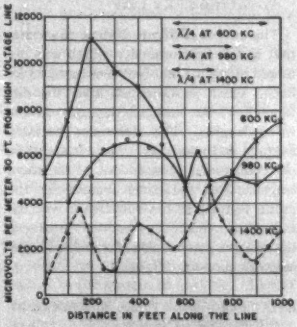
λ/4 AT 600 KC
λ/4 AT 980 KC
λ/4 AT 1400 KC
600 KC
980 KC
1400 KC
MICROVOLTS PER METER 30 FT. FROM HIGH VOLTAGE LINE
DISTANCE IN FEET ALONG THE LINE

Figure 5. Variation in radio-influence field along same section of line at three frequencies

2. Field intensity at the antenna.

3. Voltage across listener's radio receiver with antenna connected.

4. Voltage across 1,000 ohms resistance—used in place of radio receiver. (This value of load resistance has been used by Department of Transport in Canada, as it makes possible comparison of antennas on a common load basis.)

5. Line-to-line and line-to-ground voltages were measured at the 110-volt 60-cycle outlet near listener's radio receiver. The network (Figure 6 of reference 2) was used for these measurements.

6. Distances from antennas to 25-kv line, to nearest distribution line, and to 110-volt line to house.

7. Several other measurements were made such as field intensity under 132-kv line connected to the same system as the 25-kv line to which test signal was impressed; readings of field intensity at three frequencies along the same section of 25-kv line; field intensity along and at the end of a short length of street light circuit.

Results of Tests

Antenna Characteristics

The data given in Table I are for 29 antennas—all of which are of reasonably good dimensions and good construction. It was found that 45 per cent used water pipe for ground, 28 per cent had no connections to ground, and the rest used ground rods which measured in some cases several hundred ohms with direct current. The average characteristics for the antennas tested are as follows:

Length: 53 feet for L types.
Height: 22.3 feet.
Equivalent effective height: 2.83 meters (this was determined by measuring the voltage across 1,000 ohms resistance connected from antenna to ground and the field intensity near the center of the antenna).
Distance to nearest high-voltage line: 73 feet (25 kv and 4 kv).
Distance to low-voltage line: 20.7 feet (110-volt circuits).
Average coupling ratio: 0.93 (ratio of field intensity at the antenna to the field intensity 30 feet from the nearest high-voltage line).

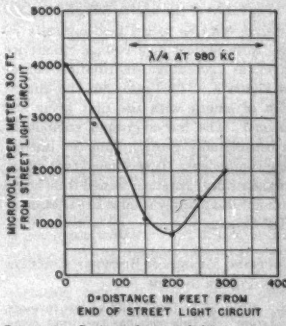

Figure 6. Radio-influence field increase at the end of a circuit

Coupling Ratio—Antenna to Nearest 25-Kv and 4-Kv Lines

The ratio of field intensity at the antenna to the field intensity 30 feet from the nearest power line is shown on Figure 2 as a percentage-distribution curve. These data indicate that the radio-influence fields at the antenna are on the average almost the same as the radio-influence field intensities at the nearest power circuit. There is no simple correlation between these coupling ratios and the distances to either high-voltage or low-voltage circuits.

Effect of Distribution Circuits on Transmission From 25-Kv Lines to Antenna

The field intensity was measured 30 feet from the 25-kv line at several points, and the average of these readings was compared to field intensities measured at the antennas. Curve A of Figure 3 shows the attenuation across an area

having distribution circuits, and so forth. The loss is 0.0182 decibels average per foot taken from 100 feet to 1,000 feet from the 25-kv line. Curve *B* of Figure 3 is for an area without any other circuits in the vicinity and gives, therefore, the attenuation for space transmission in the vicinity of a transmission line. The attenuation in this case is 0.024 decibels average per foot from 100 to 1,000 feet. Curve *B* was extrapolated after 300 feet, assuming that the field intensity varies inversely as the distance. The effect of distribution circuits is to increase the field intensity up to about twice that obtainable by space transmission alone.

Radio-Frequency Voltages on the 110-Volt Home Circuits

The ratios of the line-to-line and line-to-ground voltages to the field intensity 30 feet from nearest high-voltage circuit are given as percentage distribution curves in Figure 4. (This ratio has the dimension of length with the unit being the meter.) The line-to-ground component is considerably greater than the line-to-line component. It was noted that measurements near antennas varied from home to home in a manner similar to variation of high-frequency voltages on home circuits.

Coupling Measured Between Circuits on Power System

(*a*). From 25-kv line to 132-kv line through a station. In this case the two lines came to the station at about 90 degrees from each other, and the signal transfer was through the station. The field intensity measured under the 132-kv line was 18.5 per cent of that measured under the 25-kv line.

(*b*). From 25-kv line to 4-kv line and to telephone line. The four-wire four-kilovolt line is five to six feet away from and the telephone line 12 feet below the 25-kv line conductors. The voltage to ground on the four-kilovolt line was 8.2 per cent, and on the telephone line it was 2.4 per cent of the radio-frequency voltage on the 25-kv line.

Variation of Radio-Frequency Field Along the 25-Kv Line

The curves of Figure 5 show the variation in the field intensity which was obtained along a 1,000-foot section of 25-kv line. There is indication that the distance between maxima depends on the wave length. The difference between average and maximum values is about 50 per cent and is independent of the wave length. For the three frequencies the input voltage at the substation was the same, so that the curves represent the relative attenuation of signals over the network shown in Figure 1.

Radio-Frequency Field Measured at the End of a Circuit

It was observed during preliminary tests made with a receiver located in a car that the signal level increased whenever the end of a street-light circuit or of a four-kilovolt line was approached. In order to obtain data as to the change in the field, measurements were made along and to the end of one of these street-light circuits. The variation obtained in the field intensity is shown in Figure 6. There is a change from minimum to maximum of 5 to 1 and a quarter wave length occurs at approximately four-fifths the wave length corresponding to the velocity of light.

Conclusions

1. The radio-co-ordination problem has been resolved into the essential factors which can be determined independently. These factors can be combined to estimate the effect on radio reception of a given radio-frequency source, the characteristics of which have been measured by means of a standard test circuit.

2. Test data on the coupling factor *c* have been obtained, and it is believed that the distribution curve for the factor *c*, Figure 2, is representative for cities which have similar high-voltage and distribution lines.

References

1. Instruments and Methods of Measuring Radio Noise, C. V. Aggers, Dudley E. Foster, C. S. Young, AIEE Transactions, volume 59, 1940, March section, pages 178–92.

2. Methods of Measuring Radio Noise, 1940. Edison Electric Institute publication 69, National Electric Manufacturers Association publication 107, Radio Manufacturers Association engineering bulletin 32.

Application of Lightning Protective Devices in Wartime

I. W. GROSS
MEMBER AIEE

I. Introduction

UNDER present wartime conditions the need for conserving critical materials has been impressed upon the electrical industry with emphasis. It is for this reason that the lightning arrester subcommittee of the protective devices committee undertook a review of lightning protective devices and practices and their application to uncover and present any worth-while savings which it seems possible, practical, and reasonable to obtain. Within the short time since this project became active, it has not been possible to obtain committee agreement on all the various considerations involved. Therefore, rather than withhold from the industry the value of constructive study and suggestions already available, this paper is being presented without the sponsorship or any commitment by the lightning arrester subcommittee. It is hoped that its presentation and the discussions it will initiate will be helpful to the committee in continuing its work on this project to a conclusion. It is the purpose of the paper to give some results of a study on this problem up to the time the paper was prepared.

It should be pointed out clearly, however, that it is not the intent of this paper to imply that the suggested methods of protection and practices are suitable for universal application. Neither is it the intention to force the industry to use any of the suggested expedients where the particular conditions encountered are not suitable.

It is solely the intent of this paper to cover from a broad point of view factors in lightning-arrester protection which, if applied on an engineering basis, should result in some worth-while savings, both direct and indirect, in critical materials without lowering appreciably past standards of protection. In most cases, the protection should actually be improved.

II. Method of Approach

In undertaking this study, it was felt at first that the savings possible would be of limited extent. However, a further consideration indicated that, while an actual saving of critical metals was possible by applying lower-rated arresters where feasible, or by revamping old arresters, or reducing the length of connections and substituting other materials, there were extensive savings possible in the equipment to which the protective device was applied.

Carrying the analysis somewhat further, it was believed that a careful study of the protective problems of individual application would result in savings of both material and man hours for old installations already in service as well as for new installations being planned. At first thought, it might be assumed that the use of substitute materials for those now considered critical and the suggested reduction in arrester ratings in certain applications might introduce a greater hazard to the system as a whole. A more careful analysis of the situation, however, seemed to indicate that, in most cases, the over-all hazard to the system would be considerably reduced, although it might be expected that occasional failures of the protective devices themselves might result from the rebuilding of old equipment and the use of smaller arresters (line-type instead of station-type) and reduction of arrester rating.

The reports of some companies who had already put into use some of the methods discussed here indicated that satisfactory results were obtained. In many cases such changes from old practices had been made prior to the necessity for conserving scarce materials. The author, therefore, decided at this time to present and discuss the various proposed methods of conserving scarce materials and saving in man hours which are outlined below, since experience, limited in some cases, has been obtained already on some of the methods under service conditions. It is hoped that this paper will stimulate further interest and activity in the application of surge protective devices in a way that will save valuable critical material and man hours for the war effort.

III. Discussion of Proposed Methods of Protection

The work in recent years in getting a clearer picture of insulation strength of equipment and the protection afforded by protective devices has been presented and discussed quite thoroughly in the past and therefore will not be presented here. The lightning arrester and similar circuit-clearing devices have a very definite maximum voltage (60-cycle) rating which must not be exceeded in service without the possibility of failure of the device. In the past, many arresters have been applied to a system merely by matching the arrester rating with the system voltage without giving consideration to the actual voltage which might appear across the arrester in service. This is particularly true of solidly grounded neutral systems.

1. Reduced-Rated Arresters

The first consideration, therefore, is that of applying arresters on the basis of the highest system, or 60-cycle, voltage expected across their terminals in service. If this principle is adhered to, it is possible on many grounded neutral systems, at least, to use an arrester having a rating somewhat below, and in some cases considerably below, the line-to-line rating of the system. In the past, the entire field was covered by the general rule that on a grounded neutral system, the arrester would have a 60-cycle rating of approximately 80 per cent of line-to-line voltage. While this rule seemed to work out satisfactorily in most cases from an operating point of view, many cases exist today where an arrester of lower rating than one selected by this rule can be and has been used successfully. On a 132-kv nominal system, for example, the preferred rating for apparatus is 5 per cent higher or 138 kv, and the rating for arresters is 5 per cent above this value, or 144 kv. If the system neutral is grounded however, the industry recommendation for the arrester is 80 per cent of 144 or—the nearest standard arrester—121 kv. Thus, the use of the so-called grounded neutral arrester, instead of the full-rated arrester, on a system the neutral of which is grounded, results in a saving of approximately 20 per cent of the arrester material and cost, with considerably better protection provided. In carrying the analysis a step further, a calculation of the system overvoltage for each arrester application is made by our company, which showed in practically all cases that the overvoltage to ground does not exceed 109 kv. This results in a further

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I. W. Gross is electrical research engineer, American Gas and Electric Service Corporation, New York, N. Y.

decrease of 10 per cent in the materials and cost of the arrester. Three large companies have reported that they have been adopting this general practice of using the so-called reduced-rated arresters for grounded neutral systems for a considerable period of time with completely satisfactory results. The practice can be applied to both new installations and revamped old installations with direct savings of material in both cases.

This application of so-called "reduced-rating" arresters on solidly grounded neutral systems on the basis of the calculated 60-cycle system voltage under fault conditions instead of on the customary 80 per cent rule has resulted in savings other than in the arrester alone. It has been found possible in some cases to use equipment in the next lower voltage class, thereby using less critical material in the equipment itself.

2. Line-Type in Place of Station-Type Arresters

A second consideration relates to the use of line-type arresters in the place of station-type in certain locations and under some conditions. Several savings are possible here:

1. In the amount of material required for the smaller line-type arresters.
2. In the possibility of less structural work for supporting the arrester.

It should be appreciated, of course, that the line-type arrester has a higher voltage level of protection than a station-type, and for this reason this application may not be desirable in some cases. On the other hand, where new equipment is involved, it is often possible to use the line-type arrester instead of the station-type and still obtain adequate protection. Four large users of arresters have reported the successful application of line-type arresters in place of station-type under some conditions.

3. Protecting Equipment Not Already Protected

It might seem at first that the recommendation to add an arrester or similar protective device to equipment not now so protected is a "spending" of critical materials rather than a "saving." The broad point of view, however, is that the protection of equipment, subject to frequent hazards of overvoltage, may save that equipment from failure. It thus obviates the necessity of using critical materials for replacement of the damaged apparatus and further saves the man hours involved in building new replacement equipment or repairing the damage, as well as the man hours involved in replacement in the field.

It is not intended to imply that extensive and elaborate protective schemes be added to many pieces of equipment or in many situations where it is felt that past experience has given satisfactory performance, but a careful analysis of many situations in most companies will reveal cases where it is believed a thorough study and application of protective devices will yield considerable over-all benefits.

Cables, for example, subject to lightning require a large amount of critical material which well might be saved by suitable protection. Likewise, the protection of rotating equipment such as generators and large motors, subject to transient overvoltages, well may be given careful study, since the failure of such a piece of equipment may result in consequences more important than even the saving of critical materials. For example, the loss of generating capacity over a period of time or interruption to service to important war industry loads, although not "critical materials," is in a sense as important, if not more so.

4. Rebuilding and Revamping Old Arresters

A fourth factor to be considered is the savings of materials made possible by rebuilding or revamping old-type arresters. Several companies have reported that they have been doing work along these lines for some time. In the case of oxide film arresters which were extensively used in the past, it is general practice in a number of companies to reduce the number of cells in existing arresters, which, in effect, means reducing the arrester rating to match more nearly overvoltage conditions of the circuit where they are used. The principle involved has been discussed in the preceding paragraphs. Likewise, the changing of four-leg oxide film arresters to the three-leg type has been an accepted practice in our own company for some time, with complete success from the viewpoint of added protection and absence of arrester failure. Of course, in such cases the 60-cycle maximum rating of the remaining three legs must be checked against the system overvoltage under fault conditions. In some cases where the three-leg 60 cycle rating was too low, part of the fourth leg was left in service to supply the deficiency.

Successful rebuilding of mica-spaced and open-gap autovalve arresters has also been reported. The rebuilding of old arresters supplies added protection to equipment, where they are installed by lowering the protecting level, and also may make available some of the material removed for other arrester locations or spare parts. The rebuilding of even obsolete arresters may be warranted in some cases, if new arresters are not available. The added protection of rebuilding obsolete arresters may be justified in some cases, although the protective level may be higher than would be desired ordinarily.

5. Protective Devices Other Than Arresters

While the lightning arrester has been mentioned here quite extensively, it is recognized that there are other protective devices such as the protector tube, open-air gap, and control gap which also take their place in the matter of conserving materials. The decision as to which device to select is one of individual application and protection desired. It is believed that the characteristics of all of these devices are available or can be obtained with sufficient accuracy for purposes of application. All of these devices have been reported as having been used with satisfactory results. Whether to use one device in preference to the other in an attempt to save critical materials will probably depend in most cases on the immediate protective problem at hand and the availability of the device.

6. Connecting Leads Between Arrester and Equipment

A sixth consideration is the conducting material, usually copper, which can be saved by eliminating the ground leads from the ground end of arresters to ground. Where arresters such as station type or arresters mounted on the well-grounded structural steel of stations or steel poles are involved, the elimination in new designs or the removal in old designs of direct ground-wire leads can be accomplished without impairing the protective value of the arrester. The removal of such existing ground leads may not be highly practical, but in new installations it most certainly seems justified as a wartime expedient.

7. Critical Materials in Arrester Manufacture

Inherently, an arrester or other protective device of this type has a relatively small amount of critical material, that is, copper, iron, and aluminum. In one case at least, aluminum supporting castings have been replaced by galvanized iron. It has been suggested that the internal mechanism of the sealed gap element in

arresters could be made in whole or in part of iron in the place of brass, but since both materials are so-called "critical," the change in arrester design would be predicated probably on which may become most critical and in the arc-interrupting characteristics of a design using iron. In the design of devices, therefore, it does not appear that there is room for any appreciable saving in critical metals, and probably the manufacturers have gone about as far as they reasonably can under present conditions.

8. Proximity of Arrester to Equipment

An eighth consideration relates to the location of the arrester or protective device close to the equipment to be protected. This is now recognized as fundamental in applying overvoltage protective devices. By locating arresters this way and even relocating those now in service in the field, it is possible in some cases to save copper conductor at the ground and line leads and, at the same time, improve protection to the equipment. It is well known that under some conditions long leads in the arrester circuit permit the protective level at the equipment to rise appreciably above the level at the arrester terminals.

Cases where this proposal can be applied are at cable terminals where the arrester should be located directly across the pothead terminal rather than have a separate ground lead extending to ground, provided, of course, that the cable sheath is well grounded at the arrester location. Another case involves the location of distribution arresters one pole distant from isolated transformers or transformer banks. Such methods of attempted protection are considered of limited value in exposed locations where a long arrester ground lead is used and there is in addition a long line lead between the arrester and the transformer. In recent years the practice has been followed by several companies of locating arresters directly on equipment such as transformers, the transformer tank being provided with a supporting bracket on the tank. Arresters likewise have in some cases been mounted on the transformer covers. This suggestion can be applied both to new arrester installations and to many existing ones.

9. Shielding Stations

Another consideration applies to protection at stations where considerable electrical equipment is located and the equipment is built up of a large amount of critical material and will require replacement or repair in kind, as well as requiring a large amount of man hours and possible loss of factory output, if it should fail in service. The adequate protection of such stations seems almost a necessity. One way of greatly adding to the protection is by shielding the station as a whole, in addition to applying arrester protection. While shielding requires some critical materials such as steel, copper, or combinations thereof, it is suggested that careful consideration be given to such shielding in the light of relative importance of the equipment contained in the station. It is not recommended that all stations be shielded, but there are undoubtedly some which can initially use critical materials such as shielding wires with considerable, overall saving from a long range point of view.

10. Tests and Maintenance of Arresters

The last subject considered here centers around the idea of keeping in the best possible operating condition equipment which we now have. This means, with the lightning arrester, a high degree of careful and planned maintenance. So far as the arrester is concerned, it is suggested that special consideration be given to testing arresters wherever possible and feasible, to insure that they are in the best of condition to perform their expected functions. Several years ago recommendations were made by the AIEE lightning arrester subcommittee on methods of testing some types of arresters. Since that time, a large number of arresters have been tested, and other methods of test or refinements have been used. It cannot be urged too strongly that a special attempt should be made to keep the arresters in the best possible condition.

IV. Summary of Benefits and Savings

That there are possible savings in critical material and man hours in the more careful study and application of protective devices already installed on the existing equipment and new applications seems evident from the preceding discussion.

A. The application of arresters on the basis of their rating, co-ordinated with the overvoltage of the system, will reduce to a slight degree the number of arrester units required on new work and make available some arrester units now in service for spares or new installations.

B. By closer application of arresters on the basis of their voltage rating, better protection will be provided to the protected equipment, and this should result in fewer equipment failures and, consequently, less need for critical materials and a saving in man hours used for renewal.

C. The use of lower-rated arresters also will result in lower insulation requirements of equipment such as transformers, for example, with consequent saving in steel in the containing tanks and core and some copper in bushing studs and winding.

D. The use of line-type arresters instead of station-type, where expedient, results in a direct savings of materials in the arresters themselves, as well as in possible savings in steel-mounting members and structures.

E. Applying protection on equipment not already protected can result in indirect savings in replacement of equipment which otherwise might become faulty if not protected.

F. Rebuilding of old arresters provides greater protection to existing equipment and eliminates the requirement of critical material for new modern arresters.

G. The omission and removal of ground leads from arresters already connected to well-grounded metal structures provide critical material for scrap or other uses.

H. A well-planned shielding system for exposed stations, although initially requiring critical material, may be more than compensated for by the prevention of equipment failure in such stations.

I. Testing of existing equipment to keep it in first-class operating condition likewise may reduce to a large extent the requirements for new equipment for replacement of protective devices and equipment which may become faulty in service.

It should be kept in mind that, in applying some of these suggestions, the failure rate on the protective devices themselves may increase, but it is believed that, if the conditions of each situation are considered carefully, and action taken on an engineering basis, the net over-all effect will be of considerable benefit to the war effort.

The Auto-Blast Interrupter Switch

E. A. WILLIAMS, JR.
MEMBER AIEE

W. G. HARLOW
ASSOCIATE AIEE

Synopsis: An air interrupter switch may be defined as a nonautomatic air switch which combines the functions of a disconnecting switch with the ability to interrupt current up to a predetermined magnitude. It primarily differs in function from a circuit breaker in that it cannot interrupt overload or short-circuit currents. General specifications for interrupter switches are proposed.

The Auto-Blast interrupter switch is an air interrupter switch having each pole equipped with an arc chute into which the arc is driven by a blast of air generated automatically when the switch is opened. Interruption occurs within the chute by elongating and cooling the arc. The construction and operation of this switch is described, and test data are presented to show compliance with the proposed general specifications.

WHILE power circuit breakers are preferred for switching unit-substation and secondary-network transformers, it has been shown[1] that there is a definite economic field for metal-enclosed interrupter switches for these applications. The requirement for these switches exists because of the development of distribution systems having transformer capacity divided into a number of small banks and protected by a common-feeder circuit breaker. Economical switching provisions are necessary to provide means for disconnecting an individual transformer from a primary feeder without deenergizing the feeder.

Since an interrupter switch cannot open short-circuit current and a short circuit may occur at any time, there is always a certain degree of hazard associated with the operation of such switches. The probability of the occurrence of a short circuit in the transformer at the instant a switch is opened is remote, but the failure of a switch to interrupt the arc, for any reason, will probably result in a short circuit within the metal enclosure. Much can be done to minimize this possibility by giving due consideration to adequate design and tests. Good engineering judgment dictates the following general specifications for interrupter switches:

1. Long operating life with a minimum of maintenance.
2. Ability to interrupt current, within its interrupting rating, without arc or flame outside of the interrupting element.
3. A sufficient number of tests to demonstrate adequate safety factors in voltage, current, and operating life.
4. Speed of opening independent of operator.
5. Positive operation to prevent failure caused by partial closing and reopening.
6. An insulation level consistent with that of other apparatus in the circuit.

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E. A. WILLIAMS, JR., is in charge of switchgear device engineering, and W. G. HARLOW is designing engineer, both in the switchgear engineering department of the General Electric Company, Philadelphia, Pa.

Figure 1. The Auto-Blast interrupter switch. 15 kv, 600 amperes continuous

Impulse insulation level 110 kv. Metal enclosure and operating handle removed

Table A. Three-Phase Reactance Load Interrupting Tests

Circuit Diagram Figure 6a

Tests	*Line-to-Line Recovery Voltage (Kilovolts)	**Test Current (RMS Amperes)	Arcing Time (Half-Cycles) Minimum	Maximum	Average	Muffler	Remarks
1 to 45	14.5	4–8	0.6	1.0	0.8		
46 to 49	15.0	4–6	0.7	1.0	0.9		
50 to 92	14.5	11–12	0.5	1.0	0.7		
93 to 96	15.0	11–13	0.2	2.0	0.9	Off	
97 to 139	14.5	20–21	1.0	1.0	1.0		
140 to 144	15.0	20–23	0.5	1.5	1.0		No disturbance—cleared
145 to 186	14.5	39–48	No oscillograms				
187 to 199	15.0	40–50	0.3	1.9	1.0		
200 to 243	14.5	88–125	No oscillograms				
244 to 248	15.0	91–129	0.3	2.0	1.3		
249 to 253	14.5	165–172	1.1	1.5	1.3	On	
254 to 255	15.0	171–178	0.9	2.8	1.5		

* Average three-phase voltage.

** Two values indicate minimum and maximum current interrupted for each series of tests.

Table B. Single-Phase Reactance Load Interrupting Tests

Reactance Load—Circuit Diagram Figure 6b

Tests	Line-to-Line Recovery Voltage (Kilovolts)	**Test Current (RMS Amperes)	Arcing Time (Half-Cycles) Minimum	Maximum	Average	Muffler	Remarks
256 to 258	5.2	69			1.1		
259	5.0	93			1.7		
260	5.1	113			1.1		
261	5.1	148			1.1		
262	4.9	165			1.0		
263	4.9	196			1.0		
264	4.8	220			1.4		
265	4.8	240			1.0		
266	7.5	98			1.1		
267	14.0	55			1.1		
268 to 270	14.0	54–55			1.0	Off	
271 to 276	15.0	26–27	0.3	1.0	0.7		No disturbance—cleared
277 to 282	15.0	56–58	0.8	1.1	0.9		
283	16.0	27			1.0		
284	16.0	39			0.8		
285	16.0	52			1.1		
286	17.0	29			1.0		
287 to 288	18.0	31			0.9		
289	19.0	32			0.8		
290 to 295	20.0	33–34	0.2	0.9	0.6		
296	22.0	36			1.0		
297	4.9	250			1.8	On	
298	4.7	270			1.8		
299	4.3	290			1.9		

** Two values indicate minimum and maximum currents interrupted for each series of tests.

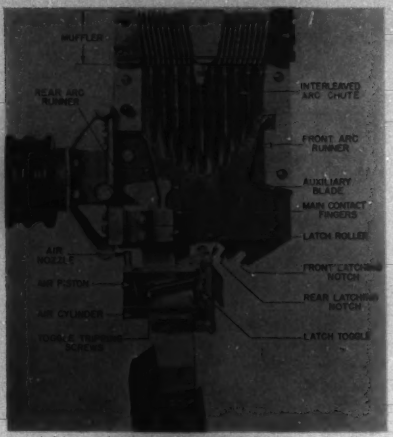
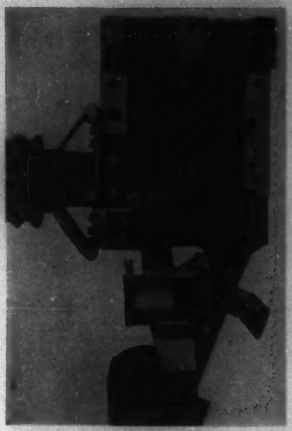


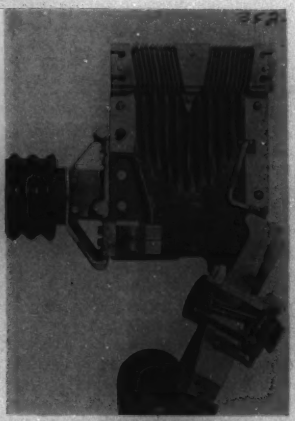
Figure 2. Cutaway views of Auto-Blast interrupter switch showing operation

(a—left). Main and auxiliary blades closed and piston at end of exhaust stroke

(b—right). Opening operation. Main blade partially open, auxiliary blade closed and piston at end of intake stroke



(c). Opening operation. Main blade partially open, auxiliary blade closed, with latch tripped and piston starting exhaust stroke



(d). Opening operation. Main and auxiliary blade partially open, latch reset and piston at end of exhaust stroke

(e). Closing operation. Main and auxiliary blade partially closed, toggle latch depressed

The Auto-Blast interrupter switch described in this paper is a new device which is intended primarily for application in a metal enclosure on the high-voltage side of unit substations and secondary-network transformers.

Construction and Operation

The Auto-Blast interrupter switch, Figure 1, is essentially a triple-pole group-operated device with three moving elements carried on a common rotatable operating shaft. The switch is arranged for mounting in a metal enclosure and for operating by means of a handle (not shown), keyed to either end of the rotatable shaft and located outside of the enclosure. In an opening operation the main switch blade opens first and, after a predetermined movement, trips a latch which releases the spring-actuated auxiliary blade. The auxiliary blade then snaps open, and the resultant arc is forced into the chute by a blast of air from a cylinder on the auxiliary blade. Figure 2 shows the construction of the switch and the relationship of the parts during successive steps of operation.

Each moving element of the switch has a pair of spaced main blades rigidly fastened to the operating-shaft insulators. An auxiliary blade and latch assembly is carried between and pivoted on the main blades at a point near the operating shaft. An air cylinder and nozzle form an integral part of the auxiliary blade, and a coacting air piston is attached to the main blades. A torsion spring normally maintains a parallel relationship between the main and auxiliary blades in which position the piston is at the exhaust end of its stroke.

Each stationary element of the switch consists of a contact and an arc chute assembly mounted on a fixed insulator. The contact assembly is made up of two spaced main contacts outside of the chute

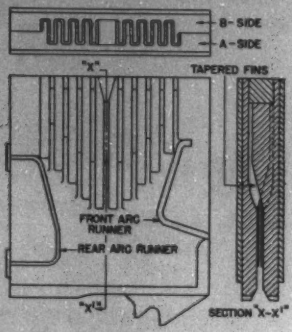


Figure 3. Interleaved arc chute

Side view with *A* side removed

and two arc runners centrally located inside the chute. The arc-chute assembly includes an interrupting element, with or without a muffler, and means for latching the auxiliary blade in the closed-circuit position during the first part of the opening stroke of the main blade.

In the closed position, Figure 2a, the main and auxiliary blades are in parallel, and the air piston is at the exhaust end of its exhaust stroke. When the operating handle is moved from the closed position, the main blade starts the opening travel,

Figure 4. Dimensions of metal-enclosed interrupter switch mounted on transformer

Impulse Level (Kilovolts)	A Width (Inches)	B Depth (Inches)	C Height (Inches)
60	29	27	43
75	35	31	43
95	38	32	44
110	43	34	45

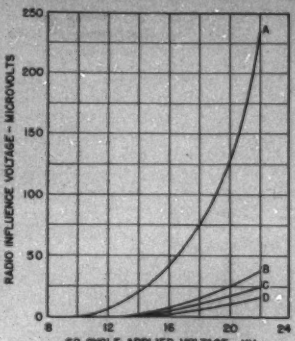


Figure 5. Radio-influence voltage tests on the Auto-Blast interrupter switch

	Impulse Level (Kilovolts)
A	60
B	75
C	95
D	110

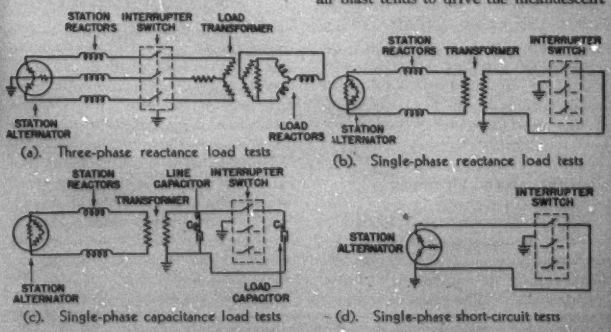
the auxiliary-blade latch engages the rear notch in the side plates of the chute assembly and holds the auxiliary blade in contact. As the main blade continues to move away from the fixed contact, the piston starts its intake stroke, and the auxiliary blade and air cylinder remain stationary until the switch reaches the position shown in Figure 2b. At this point the piston strikes and trips the toggle of the latch, Figure 2c, and the torsion spring snaps the auxiliary blade back toward the main blade and drives the cylinder over the piston forcing a blast of air from the nozzle into the arc chute. As the cylinder approaches the end of the exhaust stroke, the latch resets, the piston diaphragm covers the nozzle opening and traps air in the end of the cylinder, thereby cushioning the shock, Figure 2d. Both blades then move together to the full 90-degree open position.

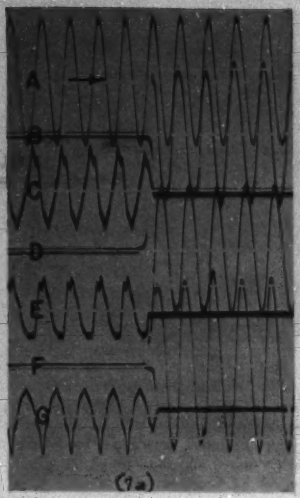
In a normal closing operation, as the operating handle is moved from the open position toward the closed position, both blades and the toggle latch assembly move together until the latch is depressed, Figure 2e, by the cam surfaces formed on the arc-chute side plates. The latch roller then successively engages the front end and the rear latching notches as the switch is moved to the closed position, Figure 2a. The location of the front latching notch is such that it is engaged by the latch roller before an arc can be established during a closing stroke. This feature prevents the possibility of failure caused by partial closing and reopening.

The interleaved arc chute, Figure 3, is similar to the chute of the Magne-Blast air circuit breaker.[3] It is formed by tapered fins alternating from either arc chute wall. The material of the chute is treated especially to be arc resistant and essentially nongas producing and nonexpendable. The entire arc-chute assembly is easily removable for inspection of contacts, without disturbing the adjustment of either the chute or the switch parts.

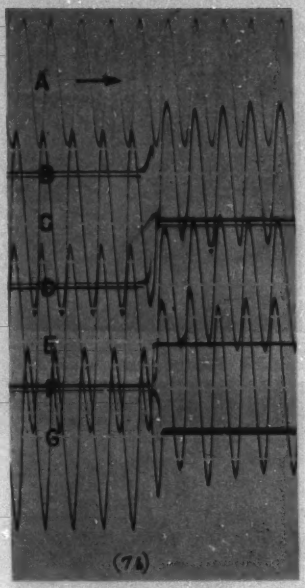
The arc is drawn in a narrow slot between the auxiliary-blade tip and the rear arc runner. As it is forced up the runners and into the chute, it progressively lengthens and encounters an increasing cooling effect as its path becomes longer. The maximum current that can be interrupted with no disturbance external to the interrupting element is a function of the size of the arc chute and of the pressure and volume of the air blast. When interrupting relatively low currents, such as transformer exciting current, the arc and incandescent gases are entirely confined within the short simple chute of Figure 3. With increased current, as indicated in the accompanying tables, the air blast tends to drive the incandescent

Figure 6. Test circuit diagrams

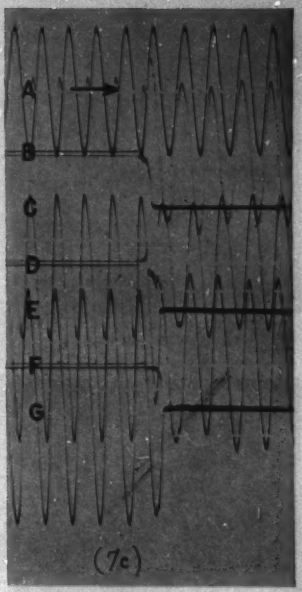




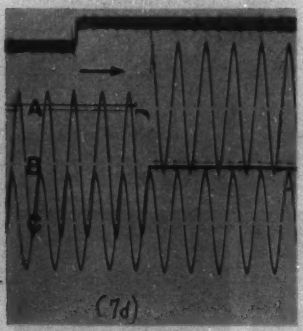
(a). Test 47
A—Timing wave
B—Voltage across switch—line 1
C—Current through switch—line 1
D—Voltage across switch—line 2
E—Current through switch—line 2
F—Voltage across switch—line 3
G—Current through switch—line 3



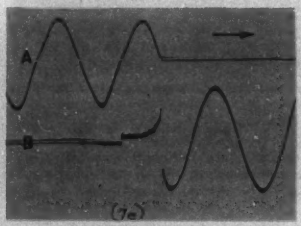
(b). Test 189
A to *G* same as (a)



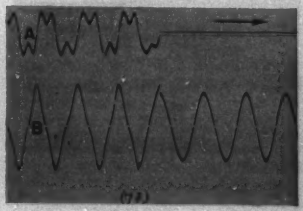
(c). Test 254
A to *G* same as (a)



(d). Test 296
A—Voltage across switch
B—Current through switch
C—Timing wave



(e). Test 299
A—Current through switch
B—Voltage across switch



(f). Test 322
A—Current through switch
B—Voltage across switch and capacitor

Figure 7. Typical oscillograms
Refer to Tables A, B, and C for data

arc gases through the short chute before adequate cooling can take place. The interruption of relatively high currents can be successfully accomplished in the same arc chute by the addition of a suitable muffler to cool further the arc gases.

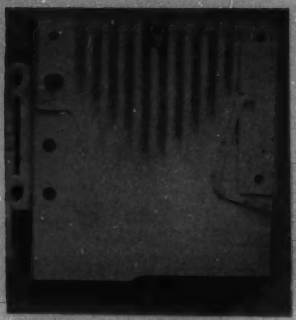
The combination of a small basic arc chute for low current and an easily attachable muffler for higher current provides the most economical arrangement for handling the complete range of current under consideration. It further provides a convenient means of increasing the interrupting ability of existing devices originally intended for the interruption of transformer exciting current only.

Since space is always at a premium, it is important that the dimensions of the switch and its enclosure be maintained at the minimum commensurate with adequate insulation levels. The required impulse-withstand test voltage is the major factor in determining the over-all dimensions of the Auto-Blast interrupter-switch enclosure shown in Figure 4. Dimensions of such magnitude must, of necessity, accompany the degree of insulation obtained.

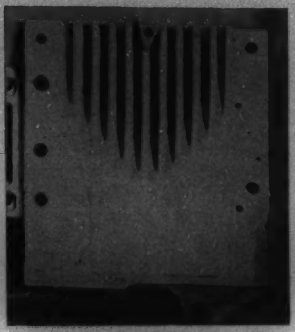
Tests

The Auto-Blast interrupter switch, mounted in a metal enclosure, has been tested thoroughly to check its conformance with the design specifications.

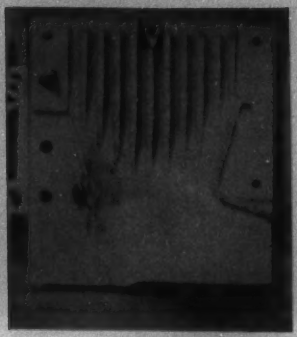
Radio-influence tests in both the open and closed positions of the switch with the metal enclosure grounded, Figure 5, show that the radio-influence levels of the interrupter switch for all classes of insula-



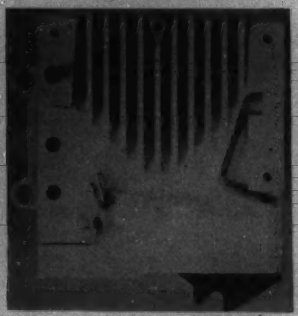
(a). After test 49



(b). After test 144



(c). After test 199



(d). After test 248

(e). After test 255

Figure 8. Arc chutes after three-phase interrupting tests

Figure 9 (below). Test 326

Attempting to open short circuit of 30,000 amperes initial, 16,400 amperes final at 14.5 kv. Arc duration 23 cycles

tion meet the limits established in the National Electrical Manufacturers Association Standards.[3]

Dielectric tests, both 60-cycle and impulse, made on the switch in the open and in the closed positions with the metal enclosure grounded, determined the insulation required and the sizes of the metal enclosures, Figure 4. These tests were made in accordance with the AIEE Standard[4] for air switches.

Interrupting tests were conducted over a two-year period to investigate a number of basic methods of interrupting transformer exciting current and load current. More than 5,000 tests showed the Auto-Blast design to be by far the most outstanding. A few of the results are shown in Tables A, B, and C with typical magnetic oscillograms in Figure 7.

Various circuits were used to cover the complete range of current and voltage. To simulate in test the most severe service conditions, a value of 20 per cent power factor was established as the maximum at which interrupting tests should be made. However, all of the reactance-

(a). Before test

(b). Switch starts to open

(c). After one cycle of arc

(d). After four cycles of arc

(e). After nine cyles of arc

(f). After 17 cycles of arc

(g). After 19 cycles of arc

(h). After test

Figure 10. Switch parts after test 326

load interrupting tests were made with the current limited almost entirely by reactance, and the power factor in all cases approached zero.

The entire series of three-phase reactance-load interrupting tests in Table A was made on one set of arc chutes and without maintenance of any kind on the switch or chutes. After each group of tests, the switch was examined, the arc chutes removed, dismantled, and photographed. The only evidence of change during the entire series of tests was a slight pitting of the arc runners and a discoloration of the arc chutes by a nonconducting oxide deposit, Figure 8. After tests the chutes were in excellent condition and were obviously suitable for at least 1,000 successful operations.

The single-phase reactance-load interrupting tests, Table B, demonstrate that the 15-kv switch, without a muffler, performs successfully at voltages up to 22 kv across a single pole to ground. The single-phase capacitance-load interrupting tests in Table C, made with and without capacitance on the line side of the switch,[8] indicate the possibility of switching capacitor banks with the Auto-Blast interrupter switch.

Short-circuit tests at 14.5 kv, Table D, were made with the switch in the circuit near the generator terminals. The switch with manual mechanism was closed with a fast positive operation against a fault current of 31,000 amperes. The switch parts were damaged, but all resulting disturbance was confined within the metal enclosure. An opening test under approximately the same short-circuit current conditions produced a very severe disturbance as shown by high-speed motion pictures, selected frames of which are reproduced as Figure 9. Flame, hot metal, and gas were blown through the ventilating louvres and through the joint between the cover and the housing. The switch parts were badly damaged as shown in Figure 10, and most parts would have required replacement before the switch could have been put back in service.

Table C. Single-Phase Capacitance Load Interrupting Tests

Single-Phase Capacitance Load Tests—Circuit Diagram Figure 6c

Tests	Line-to-Line Recovery Voltage (Kilovolts)	**Test Current (RMS Amperes)	Line-to-Ground Capacitance (Microfarads) C_1	Line-to-Ground Capacitance (Microfarads) C_2	Muffler	Remarks
300 to 307	15.0	26–33	4.4	None	Off	No disturbance—cleared
308 to 311	15.0	29	4.4	4.5	Off	No disturbance—cleared
312 to 314	15.0	57	8.8	None	Off	No disturbance—cleared
315	15.0	57	8.8	8.4	Off	No disturbance—cleared
316 to 320	15.0	57	8.8	8.4	On	No disturbance—cleared
321 to 324	15.0	115–120	17.6	None	On	No disturbance—cleared

** Two values indicate minimum and maximum currents interrupted for each series of tests.

Table D. Single-Phase Short-Circuit Tests—Circuit Diagram Figure 6d

Test Number	Line-to-Line Test Voltage (Kilovolts)	Test Current (RMS Amperes)	Operation	Remarks
325	14.5	31,000	Close	No disturbance outside of housing except slight trace of smoke from louvres
326	14.5	30,000 initial, 16,400 final	Open	Loud report with much smoke, flame, and hot metal from housing. Several bolts from lower edge of cover blown off

Conclusions

1. Interrupter switches in general should be liberally designed and rigorously tested, since any failure in normal operation probably will result in a short circuit.

2. The Auto-Blast interrupter switch fully meets all modern requirements for high insulation level, low radio-influence voltage, and adequate safety factor in interrupting ability for the service intended.

3. The interrupting element of the switch is arc resisting, essentially nongas producing and nonexpendable, thereby providing long operating life with minimum maintenance.

4. The performance of the switch is consistently uniform with an arcing time in the order of one to two half-cycles at all currents within its interrupting rating.

5. It has been demonstrated that the switch, when closed with a fast positive operation, has mechanical and thermal strength to withstand closing against short-circuit current not exceeding the short-time current rating of the switch with disturbance and damage confined within the metal enclosure.

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2. "Magne-Blast" Air Circuit Breaker for 5,000-Volt Service, E. W. Boehne, L. J. Linde. AIEE Transactions, volume 59, 1940, April section, pages 202–08.

3. NEMA Power-Switching Equipment Standards, NEMA publication 41-65, National Electrical Manufacturers Association, October 1940, rule SGB-25.6.

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Harmonics and Load Balance of Multiphase Rectifiers

Considerations in the Selection of the Number of Rectifier Phases

R. D. EVANS
FELLOW AIEE

Synopsis: This paper analyzes the operating characteristics of multiphase power rectifiers from the standpoint of harmonics, load balance, and their interrelation, and their effects on the apparatus and circuits to which they may be connected. These factors are considered in connection with selection of the number of rectifier phases, which varies from six (four for very small sizes) to combinations of six-phase units to form a much larger number, such as 36, 72, or even 108 phases. More specifically, the problems of harmonics, load balance, and number of phases are considered from the standpoint of the effects on

1. Apparatus, particularly turbine generators and capacitors.
2. The wave-shape distortion on circuits that may be important in inductive co-ordination.
3. The possibility of resonance being encountered in the supply system to amplify one or more of the rectifier harmonics.

These problems have increased greatly because of the great number and large size of rectifier installations made in connection with the war.

Determination of Harmonics in the A-C Supply Circuits

IT is a well-known property of rectifiers and inverters that they produce distortion of both voltage and current waves which appear on both the d-c load circuits and a-c supply circuits, even though the latter contains no generated harmonics. The important harmonics of rectifier installations for all except traction application are restricted normally to those in the a-c supply and are the only ones here considered.

The harmonics in the supply system resulting from the operation of balanced rectifiers or inverters include the series $(pn+1)$ and $(pn-1)$, where p is the number of rectifier phases and n is a series of integers. For power applications the number of rectifier phases is usually limited to six or multiples thereof. Thus, the harmonics of a six-phase rectifier are the 5th, 7th, 11th, 13th, 17th, 19th, and so forth; the harmonics of a 36-phase rectifier are the 35th, 37th, 71st, 73d, and so forth. Actually, rectifier circuits are not perfectly symmetrical or balanced so that some harmonics, not characteristic of the total number of rectifier phases, may be present in reduced magnitude. Thus, if a rectifier of 36 phases is operating with one six-phase unit out of service, the 5th, 7th, 11th, 13th, 17th, 19th, and so forth, harmonics will appear in the supply as well as the 35th, 37th, and so forth, harmonics which are characteristic of a balanced 36-phase installation.

Methods are available for the calculation of harmonics in the supply circuit to a rectifier.[1-3] The theoretical methods[2,3] are based on Fourier analyses, assuming that the inductance of the d-c load circuit is very high and that the impedance of the supply circuit has a linear frequency-reactance characteristic. One method[3] takes into account the loading of the rectifier, the reactance of the supply, and the amount of voltage reduction by phase control. This method gives excellent results when the assumptions upon which it is based are approached. Extensions of this method are also described[3] for application to cases where the supply circuit does not have a linear frequency-reactance characteristic. These extensions are based on finding an equivalent 60-cycle supply reactance corresponding to the actual harmonic reactance of the supply.

Heating of Generators

Generators supplying rectifiers are subjected to increased heating because of harmonics, particularly local heating in rotors. The heating problem is more important for turbine generators than for salient-pole machines, being particularly less for machines provided with damper windings. The importance of this problem arises principally in connection with generators that are loaded fully with six-phase rectifiers and is of much less importance with 12-phase rectifiers. Conversely, the problem is of negligible importance for rectifiers of more than 12 phases and for conditions where the rectifiers are a small part of the total load. A favorable circumstance in the generator heating problem arises from the fact that usually the rectifier load is of higher power factor, 90 to 95 per cent, than generator rating, 80 per cent power factor. This condition reduces excitation loss and thus provides a margin for increased loss from harmonic currents.

Heating of Capacitors

Commercial capacitors are designed to carry in addition to the rated kilovolt-amperes at fundamental frequency, 35 per cent additional kilovolt-amperes to provide for overvoltage at fundamental frequency or for harmonics. The total kilovolt-amperes of 135 per cent of rating may be made up of fundamental and harmonic kilovolt-amperes added arithmetically. Thus, a capacitor will withstand 105 per cent voltage of fundamental frequency and 112 per cent current of fifth-harmonic frequency. The designs further assume that the average fundamental-frequency voltage will not exceed 105 per cent normal and that the short-time magnitude will not exceed 110 per cent. If capacitors are applied correctly with respect to fundamental-frequency voltages, the heating limitations will rarely be encountered unless the supply is subjected to very abnormal harmonic conditions which arise principally as a result of resonant conditions.

Wave Shape

Harmonics in supply circuits which parallel communication circuits may give rise to important noise-frequency co-ordination problems. These problems have been studied extensively by the Joint Co-ordination Committees of the Edison Electric Institute and the Bell Telephone System. One result of this work has been to set up two factors which take into account the over-all influence characteristic of a power-supply circuit from the standpoint of its tendency to produce noise in an adjacent telephone circuit. Because of the different effects of electric (electrostatic) and

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R. D. EVANS is consulting transmission engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

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magnetic induction, separate factors are required, one for current and the other for voltage. These factors as applied to balanced circuits supplying rectifiers are the balanced $I \cdot T$ and $KV \cdot T$ factors; where I represents the rms balanced current and KV, the rms voltage in kilovolts between line terminals of the three-phase circuit, and T, condensed from TIF (telephone influence factor), is a factor which gives the relative weighting of the various harmonic frequencies of a power system from the standpoint of their tendency to produce noise in an adjacent telephone circuit. Two different frequency-weighting curves are commonly used in rectifier studies, namely, the 1935[4] and the 1941[5] frequency-weighting curves.* The difference in weighting results from different characteristics of the telephone circuit including terminal equipment. The principal change in the 1941 weighting from the 1935 weighting results from the substantial elimination in the later telephone receivers of a resonant point in the vicinity of 1100 cycles. At the present time both types of telephone receivers are in service and both types of frequency-weighting factors are used in co-ordination studies. While the 1941 frequency-weighting curve is expected to supersede the 1935 curve, time is required for the transition, and this has been delayed further because of the war. The shape of the 1941 frequency-weighting curve has been established, but its arbitrary scale has been delayed in order to determine for it a numerical value of the same importance as the 1935 curve. For present purposes the comparisons, based on the relative shapes of these frequency-weighting curves, are sufficient.

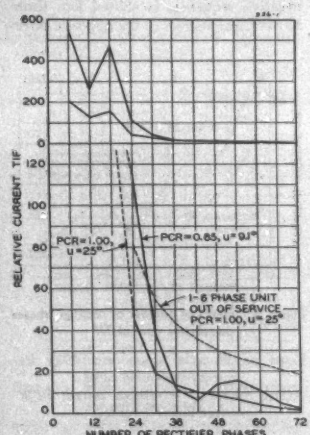

Figure 1. Effect of number of rectifier phases on relative current *TIF*

Based on 60-cycle supply and 1935 frequency-weighting curve

Actual current TIF = (relative current TIF) K' where

$$K' = \frac{I}{RI_{ac}}$$

I = D-c load current per secondary phase group

I_{ac} = Alternating current on primary side of transformer, rms value

R = Transformer ratio, primary to secondary line-to-neutral voltages

Insert: Replot of principal curves to smaller scale

An investigation, which is reported in the present paper, was undertaken to determine the relative influence of the number of rectifier phases on the inductive co-ordination problem, particularly for a number of phases beyond 12. Accordingly, calculations of the relative current TIF and relative voltage TIF for different numbers of rectifier phases from 6 to 72 were made by the method previously described. These calculations assume

1. Both 60- and 25-cycle supply.

2. Load and circuit conditions, represented by I the direct current per secondary phase group, X the commutating reactance in secondary terms, and E_n the crest value of anode-to-neutral voltage of the transformer secondary winding, of such values as to give a ratio of IX/E_n equal to 0.081, corresponding to an angle of overlap of 25 degrees.

In addition to the principal curves, which are based on no voltage reduction by phase control, that is, a phase-control ratio of one ($PCR = 1.00$), some results of calculations are given for a phase-control ratio of 0.85 ($PCR = 0.85$). The results of these calculations are plotted in the curves of Figures 1 through 6. Figures 1 and 2 give the curves of relative current—TIF for 60-cycle supply based on the 1935 and 1941 frequency-weighting curves, respectively. Figures 3 and 4 give the corresponding curves of relative voltage—TIF, respectively. Figures 5 and 6 give the corresponding curves of relative current—TIF for 25-cycle supply. Examination of the curves of Figures 1 through 6 shows important reductions in both the curves of relative current—TIF and voltage—TIF as the number of rectifier phases is increased. However, because of the high peak in the 1935 frequency-weighting curve in the vicinity of 1,100 cycles, the 18-phase rectifier with a 60-cycle supply and a 36- or 42-phase rectifier on a 25-cycle supply are less favorable than the next smaller number of rectifier phases. Because of these circumstances, it has been considered generally undesirable to use 18-phase rectifiers on 60 cycles and 36 or 42 phases on 25-cycle systems. However, the 1941 frequency-weighting curve does not have this sharp resonant point and there is a gain in increasing the number of phases throughout the practical range of rectifier application.

Effects of Supply-System Harmonics and Rectifier Load Balance and Their Interrelation

Harmonics in the supply system may have important effects on rectifier operation, particularly in producing unbalance in current between the various phase groups. Unbalancing load between phase groups also has an important effect on supply-system harmonics. Because of this interrelation between harmonics in the supply and load balance, it is convenient to consider the subject in three parts:

1. An infinite source with load unbalance.

2. An infinite source with harmonic voltages.

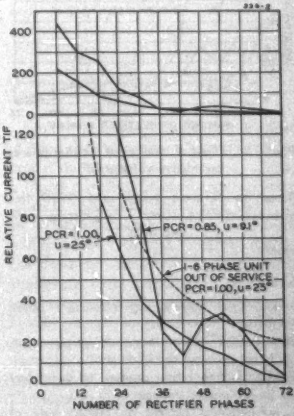

Figure 2. Effect of number of rectifier phases on relative-current *TIF*

Based on 60-cycle supply and 1941 frequency-weighting curve

Insert: Replot of principal curves to smaller scale

* In addition, there is the 1919 frequency-weighting curve that remains in use for machine wave-shape guarantees. The 1919 curve is associated with the term "telephone interference factor;" the 1935 and the 1941 curves are associated with the term "telephone influence factor;" both terms have the same abbreviation of TIF.

3. A finite source with two or more rectifiers, such that the harmonics from one affect the voltage applied to another.

Infinite Source With Load Unbalance

If one six-phase unit of a multiphase rectifier* is removed from service, the harmonic currents in the supply are affected importantly, as pointed out previously. This unbalanced condition may be analyzed by the addition of

1. A fictitious six-phase load of such magnitude and phase relation when added to the actual loads as to provide a balanced multiphase rectifier.

2. A second fictitious load, the negative of the first.

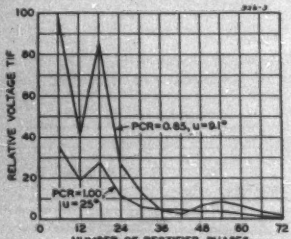

Figure 3. Effect of number of rectifier phases on relative voltage *TIF*

Based on 60-cycle supply and 1935 frequency-weighting curve $TIF = (\text{relative voltage } TIF)K'$

where

$$K' = \frac{K(\text{per cent } X)}{RI_{ac}}$$

I = D-c load current per secondary phase group

Per cent X = Transfer reactance in per cent, based on rated d-c kilowatts

R = Transformer ratio, primary to secondary line-to-neutral voltages

I_{ac} = Alternating current on primary side of transformer, rms value

Thus, this combination can be analyzed as

1. A multiphase rectifier of balanced positive load corresponding to the original number of phases.

2. A six-phase rectifier of negative load.

Both of the rectifier loads may be analyzed by the aid of the method previously described. The curves of Figures 1, 2, 5, and 6 also include some data giving the relative current telephone interference factor for a six-phase unit out of service in a multiphase rectifier. For convenience the curves have been plotted for a six-phase unit out of service with a current magnitude equal to that proportion of the total load. Actually, the harmonic currents should be increased because of the lower ratio of IX/E, that applies for such a condition.[3]

Infinite Source With Harmonic Voltages

The effect of harmonic voltages in a source, particularly at the lower-harmonic frequencies, is to increase or decrease during the conducting period the average voltage applied to the various phase groups. The practical result of this action is to unbalance the currents between the various phase groups. The phase position of the harmonic with respect to the fundamental is different for different phase groups derived by transformers from the same supply voltage. In considering the relative phase position of the harmonic voltage of a phase group with respect to its fundamental-frequency voltage, it is necessary to consider not only the higher frequency of the harmonic but also the difference in symmetrical-component phase sequence. It has been shown,[4] for the condition in which the crest of the harmonic voltage bears the same relation to the crest of the fundamental in each phase, and the sequence of the fundamental is positive, that the harmonics of order $(3m + 1)$ are of positive sequence and of order $(3m - 1)$ are negative sequence, where m is any integer. Thus, the 5th, 11th, and so forth, harmonics are of negative sequence, and the 7th, 13th, and so forth, harmonics are of positive sequence. The effect of harmonics on the average d-c voltage of a phase group can be understood more readily by reference to the diagram of Figure 7. If harmonics in the supply are such as to produce fifth-harmonic voltage applied to one rectifier phase group, as shown by the solid line curve of Figure 7, the effect is to decrease the average value of voltage on that phase group during the conducting period. If a second phase group is displaced 30 electrical degrees at fundamental frequency from the first phase group, as in a 12-phase rectifier, the phase relation of the fifth harmonic to the fundamental in the second phase group is displaced 180 degrees from the phase position of the fifth harmonic with respect to the fundamental in the first phase group. This circumstance results from the fact that the phase relation of the fundamental is shifted 30 electrical degrees in one direction while the fifth harmonic, being of negative sequence, is shifted five times 30 electrical degrees in the opposite direction. Thus, if the fifth-harmonic voltage in the supply tends to decrease the average voltage of one phase group, it tends to increase the average voltage of the other phase group in the 12-phase rectifier.

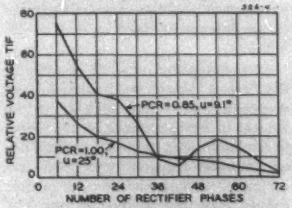

Figure 4. Effect of number of rectifier phases on relative voltage *TIF*

Based on 60-cycle supply and 1941 frequency-weighting curve

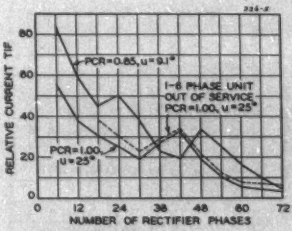

Figure 5. Effect of number of rectifier phases on relative current *TIF*

Based on 25-cycle supply and 1935 frequency-weighting curve

Actual current $TIF = (\text{relative current } TIF)K'$ (see Figure 1 for K')

If the harmonic voltage in the supply to a multiphase rectifier is shifted with respect to the fundamental, the harmonics in the secondary phase groups are shifted with respect to the fundamental, and the effects on load unbalance are altered. It is possible, therefore, that one transformer connection will be better from the standpoint of current balance than another, if harmonics of definite phase position with respect to the fundamental exist in the supply. In general, however, the phase position of the harmonic with respect to the fundamental will change at the rectifier location, and as a consequence there is little practical advantage in one transformer connection over another from the standpoint of current balance. The maximum effect of unbalancing between phase groups may be encountered in a 12-phase rectifier if

* The term multiphase rectifier is used in this paper to mean rectifiers of more than six phases.

fifth harmonics of appropriate phase relation exist in the power source. If rectifiers of more than 12 phases are supplied from a source with a fifth-harmonic voltage, the various rectifier units will carry loads between the two extremes for maximum load unbalance.

The maximum unbalance between displaced rectifier phase groups that can result from a fifth harmonic in the supply can be estimated from the equation:

$$\text{per cent } I_{un} = \frac{20 \text{ (per cent } E_5)}{\text{per cent regulation}} \quad (1)$$

where

I_{un} = the unbalance current per rectifier in per cent of normal current per phase group

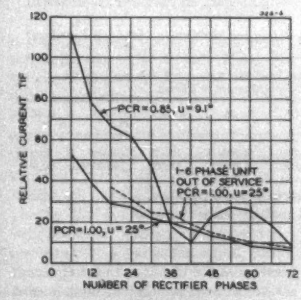

Figure 6. Effect of number of rectifier phases on relative current *TIF*

Based on 25-cycle supply and 1941 frequency-weighting curve

per cent E_5 = the fifth harmonic voltage in supply in per cent of fundamental

per cent regulation = the regulation of rectifier and transformer but not of common supply to the various phase groups, in per cent

Thus, the unbalanced current in per cent is two to five times the per cent fifth-harmonic voltage per cent in the source for the usual regulation conditions of from eight to four per cent.

The effect of a seventh harmonic in the supply is quite similar to that of a fifth harmonic. However, the seventh harmonic is usually of smaller magnitude and, therefore, has smaller effect on load balance. Furthermore, a greater magnitude of the seventh harmonic is required to produce the same amount of unbalance, because the uncompensated part of a shorter half-cycle of the harmonic must be averaged over the same conducting period.

Several years ago an analysis was made of a case where load unbalance was observed on a 12-phase, 3,000-kw rectifier. In this particular installation, four separate multianode tanks were supplied by a quadruple-zigzag 12-phase transformer connection. Harmonics in the supply voltage, both as to magnitude and phase position with respect to the fundamental, and the difference in regulation of the different phase groups were measured and the results compared with tests. The calculations based on the foregoing analysis indicated correctly which phase group should carry the heavier load. The magnitudes of the fifth-harmonic voltage and the unbalanced current are given in Table I.

The calculations were made from harmonic analyses of polar oscillograms of the supply-voltage wave, which gave

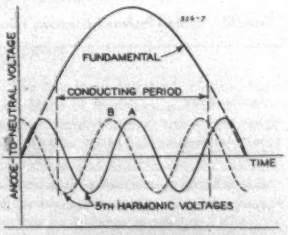

Figure 7. Diagram showing phase position of fifth harmonic to fundamental-frequency voltages for (*A*) maximum and (*B*) zero load unbalance of rectifier groups in 12-phase connection

both magnitude and phase position of the fifth harmonic with respect to the fundamental. For test 2, the phase position of the fifth-harmonic voltage was within four fundamental degrees of that position which theoretically should give the maximum unbalance for that magnitude of harmonic voltage.

Finite Source With Unbalanced Rectifier Loads and Harmonics

When multiphase rectifiers are operated from a supply system of negligible reactance, the unbalanced load resulting from the disconnection of one six-phase unit produces harmonic currents through the source corresponding to the fictitious negative six-phase load as previously pointed out. However, the outage of one six-phase unit does not affect the operation of the other six-phase units for the case of an infinite source. Consider now the case with a finite source. The effect of the harmonic current from the fictitious negative six-phase load corresponding to one unit out of service produces a harmonic voltage drop impressed on the other units which may be connected in parallel with the one that has been removed from service. Several effects may be noted. One effect of the harmonic impedance through the source is to divert part of the fictitious load current from the source to the other rectifier units. The effect may be viewed as being produced by the negative harmonic-voltage drops impressed on the remaining six-phase rectifier units as a consequence of the fictitious negative load. The result in any case is to reduce the harmonic currents flowing through the source to an amount that is less than would be expected from the greater equivalent reactance of the rectifier and supply system.[5]

Table I. Effects of Fifth-Harmonic Voltage on Rectifier Load Balance

Test	Fifth Harmonic Voltage	Unbalanced Current Per Phase Group—Per Cent	
		Calculated*	Measured
1	2.4	±6.5	±(6.5 to 7.6)
2	1.9	±5.6	±6.2

* From harmonic analysis of voltage wave.

From a practical standpoint the effect of these unbalances may be very important if they were allowed to exist. Thus, a 15 per cent fifth-harmonic voltage may produce sufficient unbalancing effect as to substantially remove the load from one six-phase unit and to nearly double the load on another. However, such conditions would normally not be allowed to remain because the voltage on the most heavily loaded six-phase unit would be reduced by phase control. This would have the effect of more nearly balancing the loads of the several six-phase units. The unbalancing effect, however, may be important if the momentary currents exceed breaker settings.

The effect of a unit out of service on a multiphase rectifier is, of course, to increase the wave-shape distortion of the supply and to increase the load unbalances. The results vary for the particular systems depending upon the number of units and reactance of the individual units and the reactance of the supply system at the harmonic frequency. The range of conditions is so great that it is scarcely practicable to generalize on the results that may be obtained. Reference, however, may be made to Marti and Taylor[4] and to the work of the Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System, which has given considerable attention to this problem.[7-9]

They show that the increase in the $I \cdot T$ products for 30- and 60-phase rectifiers with a unit out of service varies from three to five times these factors for normal balanced conditions. Because of this, there is little advantage in using more than, say, 36 phases, unless the total rectifier load is large, or unless the possibility of resonance in the supply in the vicinity of 36th harmonic is anticipated.

Resonance in the Supply System

The harmonics produced by rectifier operation are of much greater importance if the supply system is resonant for one of the rectifier harmonics, the lower frequencies being more likely to be important from the standpoint of effect on apparatus and higher frequencies from the standpoint of inductive co-ordination.

Table II. Harmonics Present for Rectifiers of Various Phases

Harmonic	6-Phase	12-Phase	18-Phase	24-Phase
5	x			
7	x			
11	x	x		
13	x	x		
17	x		x	
19	x		x	
23	x	x		x
25	x	x		x
29	x			
31	x			
35	x	x	x	
37	x	x	x	
41	x			
43	x			
47	x	x		x
49	x	x		x

The harmonics that may be impressed upon the supply system for 6-, 12-, 18-, and 24-phase rectifiers under balanced conditions are shown in Table II for harmonics as far as the 49th. The number of frequencies of 49th harmonic and below that may be present for balanced operation are 16 for 6-phase, 8 for 12-phase, 4 for 18-phase, and 4 for 24-phase rectifiers. Thus, there is much less chance of resonance for rectifiers of the larger number of phases. However, if a six-phase unit is out of service, the harmonics that may be present are the same as for the six-phase rectifier, although the magnitudes are lower than for full six-phase operation. From the standpoint of chance for resonance when one unit is out of service, there is a difference between two 24-phase rectifiers if one is made up of four six-phase units or two 12-phase units.

Frequently capacitors are used in conjunction with large industrial rectifiers supplied over long transmission lines for the purpose of increasing voltage level, thus increasing the load power factor and the amount of power that can be handled. These capacitors may increase the opportunity for producing resonance, particularly at the time when a rectifier unit is out of service. Consequently, special attention should be paid to the harmonic problem for installations involving multiphase rectifiers and capacitors.

Capacitors

In themselves capacitors generate no harmonic voltages, but they affect harmonic voltages and currents from other sources only because of the relation of their harmonic reactance to that of the connected system. Large capacitors on the supply side of rectifier transformers tend to provide a short-circuit path for the higher harmonics incidental to rectifier operation. For the lower-frequency rectifier harmonics, large capacitors may form a resonant path with the source which may result in larger harmonic currents in the source and in the capacitor than in the rectifier transformers themselves. Increasing capacitor kilovolt-amperes beyond a certain value at a rectifier location will decrease voltage telephone interference factor. This is an effect with capacitors and harmonics from rectifiers that is analogous to that pointed out by Feaster and Harder[18] for the case of capacitors and harmonics from transformer magnetizing current.

Table III. Typical Preferred Minimum Kilowatt Rating for Multiphase 600-Volt Rectifiers*

Rectifier Units	Minimum Preferred Rating—(Kilowatts) Total Number of Phases						
	6	12	18	24	30	36	42
1,500 kw—6 anodes	1,500	3,000	4,500	6,000	7,500	9,000	10,500
3,000 kw—12 anodes	3,000	3,000**	9,000	6,000**	15,000	9,000**	21,000

* Based on 6-phase transformers and phase shifters for the larger number of phases.

** Based on 12-phase transformers and phase shifters for the larger number of phases.

Depending upon conditions, it may be theoretically desirable to modify the harmonic-impedance characteristic of a shunt capacitor so as to make it

1. Provide a short-circuit path for harmonics originating in the rectifier.

2. Provide an open-circuit path to a particular harmonic originating in the system.

The short-circuit path can be obtained by adding a reactance in series relation with the capacitor of such value as to tune in series resonance for the desired frequency. Thus a reactance of four per cent at fundamental frequency on the capacitor-bank rating is required for series resonance with the entire bank at fifth-harmonic frequency. Such a reactor will increase by four per cent the fundamental-frequency voltage impressed across the capacitor, a circumstance that should receive consideration in the design and application of the capacitor. To make the shunt capacitor operate as an open circuit to a particular harmonic frequency, the capacitor may be divided into two parts with a reactor of appropriate value placed in series with one of them. Thus for a parallel-resonant combination at the fifth-harmonic frequency, a reactor of 16 per cent at fundamental frequency on the bank rating would be required for connection in series with one half of the capacitor bank. This reactor would increase the fundamental-frequency voltage applied to that section of the capacitor by eight per cent.

Where large capacitors are connected in parallel with large multiphase rectifiers supplied by transmission systems, it is particularly desirable to give careful consideration to the harmonic problem. The effects for the lower frequencies should be studied analytically, and by field tests which should give, if possible, the magnitude of the fifth-harmonic voltage in the supply and the harmonic-frequency impedances. With this information available, the capacitor application should be studied to determine what characteristic at harmonic frequency should be employed. It appears possible but unlikely that in a few installations the subdividing of the capacitor into sections tuned for various frequencies will be found desirable.

If the capacitor is supplied through a transformer (or autotransformer) and connected to the bus which supplies rectifier transformers, the effect is equivalent to putting a reactor in series with the capacitor and thus to tune it for

some (not necessarily integral) harmonic frequency of the supply system.

Available Number of Phases

Standard ignitron rectifiers in the 600–700 volt class are available in ratings up to 10,000 amperes. Typical minimum preferred kilowatt ratings for a given number of rectifier phases for large loads, as in electrochemical service, are listed in Table III, which is based on the use of 1,500-kw 6-anode and 3,000-kw 12-anode assemblies. The 3,000-kw unit is, of course, more economical than the smaller unit and should be used where total load, spare capacity, and similar considerations permit.

In industrial applications using smaller ratings, fewer anodes are required, and it becomes correspondingly more expensive to provide many phases. The possible combinations depend upon the load to be carried, the requirements for spare capacity, and the additional expense that may be justified for additional anodes. Table IV has been prepared to indicate the range and characteristics of combinations for various loads and number of phases. In some cases combinations with different number of transformers are listed for a particular rating. Since the cost of the installation will increase with the number of transformers, Table IV also gives an order of preference for the various combinations from the operating point of view aside from wave shape.

Table IV. Combinations for Various Loads and Number of Phases

Rectifier Rating (Kilowatts) 600–700 Volt Class	No. of Transformers 6-Phase	12-Phase	24-Phase
750	1		
1,000	1		
1,500	1		
2,000	1	1*	
3,000	1	1*	
5,000	1	1*–2	3**
6,000	1	1*–2	3**

* 12-phase operation by the use of one quadruple-zigzag transformer.

** 24-phase operation by the use of two quadruple-zigzag transformers and phase-shifting transformer.

Summary

The harmonic and load-balance characteristics of rectifiers and their complicated interrelations have been analyzed. The effect of source harmonics on rectifier load balance has been shown. Curves giving the effect of a wide range of rectifier phases on wave-shape distortion have been presented. The factors which should receive consideration in the selection of the number of rectifier phases have been outlined.

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A Vertical-Flow Compressed-Air Circuit Breaker and Its Application on a 132-Kv Power System

H. A. P. LANGSTAFF
MEMBER AIEE

B. P. BAKER
MEMBER AIEE

Synopsis: The compressed-air circuit breaker for indoor power-house service is becoming very popular. However, its use for high-voltage outdoor service is still in the field-trial stage. Several high-voltage porcelain-clad circuit breakers of American design are now in service, and their performance is being watched carefully. A 138-kv 1,500,000-kva three-pole breaker has been installed at the Kittanning substation of the West Penn Power Company. Before installation its interrupting ability was checked to 5,900 amperes with full 132 kv on a single-pole unit and on a circuit with a transient recovery rate of 3,100 volts per microsecond. The mechanical operation was tested with the breaker in a heavily iced condition at −14 degrees Fahrenheit. The air-supply system was tested at −4 degrees Fahrenheit, and both were found to operate satisfactorily.

The breaker was installed on the most active line of the West Penn Power Company system. During the three months following its installation it had 41 operations, five of which were on faults. Its operation to date has been satisfactory in every detail, and it is hoped that this new device will meet operating requirements and reduce materially the time outage for servicing such apparatus.

I. Introduction

THE circuit-breaker art, almost from the time of its beginning, has depended upon the use of oil as an interrupting medium. Its use has permitted this country to develop a power system whose expanse and kilovolt-ampere concentrations are equaled no other place in the world. However, during the past four years, the interest in and the acceptance of compressed air as an interrupting medium has increased at an accelerating pace.

A new type of compressed-air circuit breaker for powerhouse indoor service, utilizing a transverse blast, has been developed to cover the range of kilovolt-amperes from 500,000 to 2,500,000.[1–3]

Possibilities of the high-voltage compressed-air circuit breaker for outdoor service in America have been carefully considered and found attractive, but the advantages and disadvantages could best be definitely established by outdoor field installation and trial. Therefore, a breaker was designed, built, and tested in the Westinghouse high-power laboratory[4] and installed in August at the Kittanning substation of the West Penn Power Company.

II. Application

West Penn Power Company's 1940 plans provided for a 132-kv three-bay extension to their major switching station segregated from the existing structure. The use of three oilless breakers to eliminate fire hazard and reduce the time element for servicing was the objective. Such breakers were not available to meet the construction schedule. However, it was decided that operating experience should be obtained with such breakers; this resulted in the placing of an order in January 1941 for one vertical-flow compressed-air three-pole fully automatic 1,500,000-kva 138,000-volt breaker which was to be installed on a circuit where the greatest amount of operating experience would be secured which might be representative throughout the system. The circuit selected was already controlled by an oil circuit breaker equipped with impedance networks, provided with carrier line-current relaying and included in differential bus protection. The breaker specifications, therefore, included capacitors to replace the impedance networks, arrangement for mounting carrier wave trap, and double-ratio double-winding double-core current transformers. The inherent design located the current transformers on the line side of the breaker which therefore left the major portion of this breaker connected to the bus and included in differential protection, which was considered satisfactory. The design is such as to permit future automatic reclosing and single-pole operation.

The circuit controlled extends over a 30-mile wood-pole line to a switching station where it interconnects with the Penn-

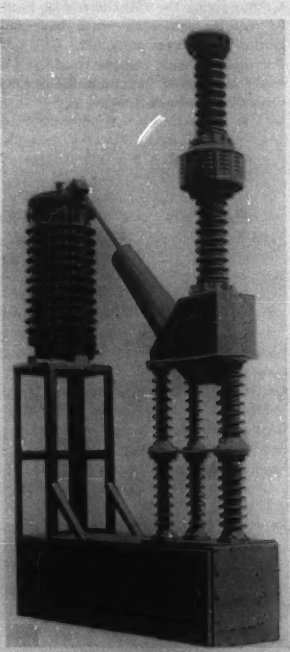

Figure 1A. Single-pole unit of a three-pole 138-kv 1,500,000-kva compressed-air circuit breaker

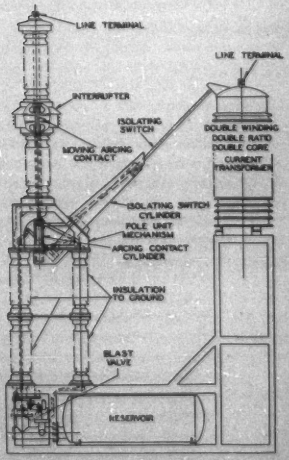

Figure 1B. Schematic drawing showing side elevation of the breaker in Figure 1A

Paper 43-51, recommended by the AIEE committee on protective devices for presentation at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943. Manuscript submitted November 27, 1942; made available for printing December 21, 1942.

H. A. P. LANGSTAFF is electrical engineer, electrical engineering department, West Penn Power Company, Pittsburgh, Pa., and B. P. BAKER is development engineer, switchgear engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

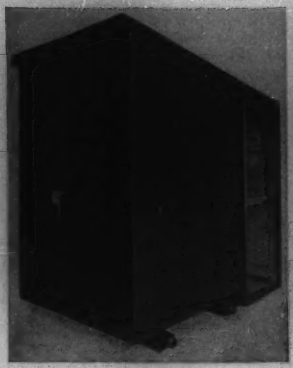

Figure 2A. Compressor house and 1,000 pounds per square inch storage system

Figure 2B. Compressors and driving motors mounted on the left side of the center aisle of the compressor house

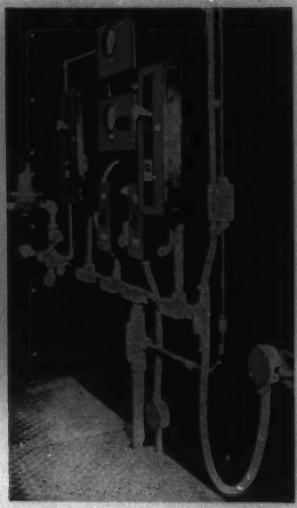

Figure 2C. Motor controls and pressure governors mounted on the right wall of the compressor house

sylvania Electric Company's system. From that point the circuit extends over 43 miles of wood-pole construction to the Keystone system of the West Penn Power Company at Ridgway, Pa.; thence again over 38 miles of transmission line, where it extends and interconnects at Warren, Pa., with the Pennsylvania Electric Company's system.

The application of this breaker is generally in line with recommendations of the action of January 27, 1941 of the Joint Committee of the Edison Electric Institute, Associated Edison Illuminating Companies, and the National Electrical Manufacturers Association, which was later followed and agreed upon in their October 24, 1941 decision, recommending field service installations on a selected set of ratings. This development holds promise of effecting savings in critical materials.

III. Description

Figure 1 shows both a picture and a schematic diagram of a single-pole unit of the 138-kv breaker. The air-storage reservoir is mounted in a simple frame which also houses the blast valve and the valves which control air for opening and closing the breaker.

At one end of the frame is mounted a porcelain clad Inerteen-filled wound-primary current transformer. The double secondary, double winding, and double core provide for bus differential protection and standard line protection, using only one transformer unit per phase. The transformer forms one line terminal of the breaker and supports the stationary contact of the isolating switch. At the other end of the frame are mounted three tubular porcelains which provide insulation to ground and form a tripod support for the pole-unit mechanism. One of these porcelains carries the air blast; the other two carry air for opening and closing the contacts respectively.

The pole-unit mechanism consists essentially of two simple cylinders and pistons. The one mounted vertically operates the arcing contact within the interrupting device, and the other mounted at an angle operates the isolating switch. Both are very fast and pneumatically interlocked, so that the circuit is always opened on the arcing contact and closed on the isolating switch.

The double-orifice vertical-flow interrupting element described fully in another paper[4] is supported by the pole-unit-mechanism housing between two identical porcelain columns.

With the breaker in the closed position, the circuit is complete from the top of the upper interrupter porcelain through the interrupter, the pole-unit mechanism, the isolating switch, and current transformer.

Bleeder valves are provided to allow a continuous trickle of dry air through all three porcelain columns, thereby preventing breathing and keeping their inner surfaces in better operating condition.

Table I. Interrupting Tests on a Single-Pole Unit of a Three-Pole 138-Kv 1,500,000-Kva Compressed-Air Circuit Breaker

Tests June 5, 1942, at the East Pittsburgh High-Power Laboratory. Witnessed by Engineers of the West Penn Power Company

Test	Applied Voltage (Kilovolts)	Recovery Voltage (Kilovolts)	Amperes Interrupted (RMS)	Amperes Closed (Crest)	Reservoir Pressure (Pounds Per Square Inch)	Arcing Time (Cycles)	Circuit-Transient Recovery Rate (Volts Per Microsecond)	Frequency Cycles Per Second	Type of Operation
*1	120	114	1,410		350	0.8	1,100	60	O
2	120	116	1,150	1,560	350	0.7	1,100	60	CO
3	120	112	2,540		350	1.2	1,550	60	O
4	120	108	2,030	4,330	350	1.5	1,550	60	CO
5	120	110	3,160		350	1.0	2,000	60	O
6	120	107	2,820	7,150	350	0.8	2,000	60	CO
*7	120	109	4,830		350	1.7	2,600	60	O
†8	120	108	4,400	10,000	350	1.3	2,600	60	CO
9	44	41.5	2,400		350	1.4		60	O
10	88	81.0	5,650		350	1.6	2,300	60	O
11	88	80.0	4,800	11,800	350	1.0	2,300	60	CO
*12	88	82.0	6,750		350	1.6	2,500	60	O
13	88	80.5	5,840	8,050	350	1.7	2,500	60	CO
14	88	83.0	7,000		350	1.0	2,500	60	O
15	88	80.0	5,410		350	1.0		60	O

* Oscillograms shown in Figure 4. † Oscillogram shown in Figure 5.

Figure 3. A three-pole 138-kv 1,500,000-kva compressed-air circuit-breaker installation at the Kittanning substation of the West Penn Power Company

The three poles are mounted separately and are mechanically independent but are simultaneously electrically controlled from a single housing which contains all relays, gauges, and so forth. Their operation is synchronized to within a cycle, and they may be converted easily to provide high-speed reclosing for either segregated or three-pole service. All control wiring is enclosed within the tank enclosure and supporting structure.

Figure 2 shows the air-supply system which consists of an insulated heated house containing two 1,000-pounds-per-square-inch compressors separately driven and operated independently or in parallel, each feeding through separate coolers into a battery of five 1.5-cubic-foot storage bottles. These bottles are connected through another cooler to a second battery of five bottles. All are used as storage capacity at 1,000 pounds per square inch from which air is supplied through a pressure-reducing valve to the breaker reservoirs where it is stored at 350 pounds per square inch. By compressing air to 1,000 pounds per square inch, cooling, and then expanding to 350 pounds per square inch, air sufficiently dry for satisfactory operation of the breaker is secured. Preparations are being made to measure periodically the moisture content of the air under varying atmospheric conditions.

The air-supply unit is mounted adjacent to the breaker, as shown in Figure 3, and connected by means of a one-inch copper air line to the middle pole unit from where it distributes through the respective control valves to each of the two outer pole units. From the central-pole control cabinet, air passes through a protective valve which is arranged to allow air to flow forward freely after the pressure has reached a predetermined value, but to limit the flow in the forward direction in case it exceeds a predetermined amount, which would be the case with a fouled valve or burst connection. A check valve is also incorporated in this protective scheme to guard against a reverse flow of air.

Three pressure-responsive switches are connected to the common air line to provide signals guarding against the functioning of the breaker with insufficient air pressure. One switch provides alarm when pressure drops below 250 pounds per square inch, another opens the closing circuit when pressure drops below 240 pounds per square inch, and the third opens the tripping circuit when the pressure drops below 225 pounds per square inch. These switches are so connected in the control circuit that, once an operation is initiated, it will be completed without interference from the pressure switches. Settings are such that, if there is sufficient pressure to allow closing, there will be also sufficient pressure to enable the breaker to open immediately in case of a fault.

IV. Factory Tests—Interrupting Tests

One pole of this breaker was tested in the Westinghouse high power laboratory[4] and witnessed by representatives of the West Penn Power Company. Table I shows this series of 15 short-circuit tests, including both opening and closing–opening operations with 120 and 88 kv respectively across the single-pole unit. The maximum current interrupted at 120 kv was 4,830 amperes, and 7,000 amperes at 88 kv. There was practically no visible disturbance during the opening operation of these tests, but a limited amount of arcing was noticeable at the final closing position of the isolating switch. The air discharge on opening operations was quite noticeable but not at all serious and did not increase with the increase of kilovolt-amperes interrupted. After the tests, the arcing and isolating contacts were all inspected and found to be in excellent condition.

Figure 4 shows three typical oscillograms of the opening operations.

Figure 5 shows a typical oscillogram of a closing–opening operation.

Table II shows a series of six opening operations with 132 kv across a single pole of the 138-kv breaker. The reactance of the circuit was adjusted to give 4,800 amperes with a circuit transient recovery rate of 2,800 volts per microsecond. The pressure in the reservoir was decreased after the first two tests, so that on the last test 4,400 amperes were interrupted with 225 pounds per square inch.

Figure 6 shows the magnetic and cathode-ray oscillograms of a single-pole unit interrupting 5,900 amperes with full 132 kv applied to its terminals. The circuit transient recovery rate was 3,100 volts per microsecond. The arcing time was 1.2 cycles.

These tests have not extended the limits of kilovolt-amperes interrupted on this type of interrupter.[5] However, they were made to demonstrate the adequacy of this breaker for 138-kv 1,500,000-kva service.

V. Mechanical Tests

The high-pressure air system was tested at 2,000 pounds per square inch, and the low pressure reservoirs at 800 pounds per square inch. The storage tanks met the state safety code and inspection requirements and carried their approval before assembly in the breaker.

At 350 pounds per square inch, the closing time for the isolating switch is approximately one-fourth second. The

Table II. Interrupting Tests With 132-Kv Initial Voltage, 60 Cycles, Applied to a Single-Pole Unit of a Three-Pole 138-Kv 1,500,000-Kva Compressed-Air Circuit Breaker

Test	Recovery Voltage (Kilovolts)	Amperes Interrupted (RMS)	Reservoir Pressure (Pounds Per Square Inch)	Arcing Time (Cycles)	Circuit Transient Recovery Rate (Volts Per Microsecond)
1	121	4,880	350	0.8	2,800
2	120	5,100	350	0.8	2,800
3	120	4,600	300	1.0	2,800
4	120	5,000	275	1.1	2,800
5	120	4,700	250	0.8	2,800
6	118	4,400	225	1.6	2,800

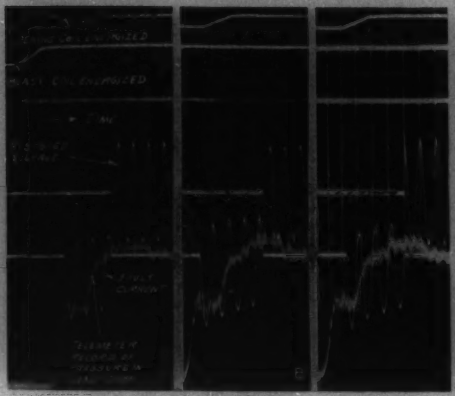

Figure 4. Magnetic oscillograms from Table I

Figure 5. Magnetic oscillogram from Table I

Currents and voltages—rms (AIEE Standards)

A. Fault current 1,410 amperes; recovery voltage 114 kv

B. Fault current 4,830 amperes; recovery voltage 109 kv

C. Fault current 6,750 amperes; recovery voltage 82 kv

three isolating switches reach the closed position within one cycle of each other. The time from rise of blast-coil current to parting of the arcing contacts is approximately six cycles. The three arcing contacts part within 0.6 cycle of each other. The spread is increased 0.1 cycle as the operating pressure is decreased to 270 pounds per square inch. The opening of a closing–opening operation increases the spread between the arcing contacts by another one- or two-tenths cycle.

VI. Low-Temperature Tests

The operation of the air-supply system at low temperatures was checked by placing it in a cold room with subzero temperature and operating it periodically for several days. Air was supplied to the compressor from outside the cold room, so that moist summer air at 85 degrees Fahrenheit was being compressed. The connection necessitated leaving ajar the door of the compressor cubicle; as a result, the temperature in the compressor cubicle reached 16 degrees Fahrenheit when the cold room temperature was −4 degrees Fahrenheit. At the end of the test, the air in the storage system was discharged through the pressure-reducing valve, with no tendency to foul its operation.

Everything functioned normally except a check valve in a cooler, which failed several times to prevent pressure from getting back to the compressor. This produced no evidence of trouble and was detected only by opening the drain valve on the compressor.

Figure 7 shows a single-pole unit of this breaker iced in a cold room at −14 degrees Fahrenheit. The tests at low temperatures extended over five days. However, in order to check its operation under the most severe conditions, the compressor was placed outside the cold room and moist warm summer air was pumped directly into the breaker, without going through the usual stages of compressing and then re-expanding in order to eliminate the moisture. Warm water

Figure 6. Cathode-ray and magnetic oscillogram of a single-pole 138-kv breaker operating with 132 kv across its terminals

Fault current 5,900 amperes; applied voltage 132 kv; circuit transient recovery rate 3,100 volts per microsecond

Figure 7. A single-pole 138-kv compressed-air circuit breaker iced for mechanical and electrical tests at −14 degrees Fahrenheit

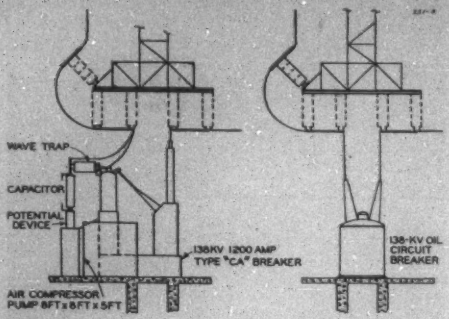

Figure 8. On the right is shown an oil circuit breaker located in the switchyard, and on the left is shown the way in which the compressed-air breaker and its accessories were arranged after the oil breaker was removed

was directed on the guide and packing gland through which the disconnecting blade slides, while the breaker was opened and closed. Thus the valves and all operating parts were thoroughly wetted. The temperature was then dropped to −14 degrees Fahrenheit and, by means of an intermittent spray, the breaker was iced as shown in Figure 7.

Upon energizing the opening valve, the operation of the contacts appeared normal, and the isolating blade apparently functioned as though no ice at all were present. Its normal average speed of 24 feet per second was recorded.

While the breaker was still iced, 132 kv was applied across the insulation ground for two minutes. Some corona was observed on the ends of icicles, but no flashover resulted.

VII. Installation

The complete breaker was trucked about 45 miles to the Kittanning substation on July 16, and, after assembly of the pole units in the vicinity of its permanent location, the oil breaker was removed, and within seven days the air-blast breaker was installed, miscellaneous changes were made, and it was tested and placed in service. Approximately 1,400 man-hours were spent on the entire job. The miscellaneous changes consisted of removal of the capacitors from the breaker assembly, rearrangement of controls, fittings, and so forth. The manufacturer's design met all general specifications, but the three capacitors were relocated and connected to the station bus to provide bus potential for all 132-kv relaying, synchronizing, and so forth. The original capacitor and carrier wave-trap installation was retained. Figure 8 shows an installation comparison of the oil breaker with that of the air-blast unit. The latter shows the capacitor with one wave trap in place as originally planned. All three poles of the breaker and the air-compressor unit have been installed within the oil-circuit-breaker bay, all of which are located on an elevated concrete platform.

The complete functioning of the entire unit was checked with the following results. With the air compressors out of service and the air-storage system normal, six opening operations and five closing operations were obtained in less than six minutes. It is recognized that this sequence should be used only in an emergency, since the charging of the breaker reservoirs from low bottle pressure decreases the effectiveness of the drying cycle. However, after operating the breaker with improperly dried air, its Megger readings had not decreased, and the breaker was placed on the 132-kv line without evidence of trouble. With the high-pressure system disconnected, the breaker completed an opening operation, followed immediately by a closing–opening operation, using air only from the pole-unit reservoirs.

It has not been found convenient to make short-circuit tests on the system because of the importance of the interconnection and because of the duty to which the breaker can be subjected being limited to about 1,000,000 kva. During the three months following its installation there was a total of 41 breaker operations, five of these being automatic as a result of line faults. All of these have been faults to ground with current values limited to not more than 3,000 amperes. All operations have been quite satisfactory with no noticeable system disturbance and without evidence of any breaker distress.

Included in the preceding operations there have been a number of cases where the charging current of the unloaded open end line has been interrupted with no noticeable disturbance.

The trickle of air through porcelain columns requires about one hour's operation per day for one compressor. A rather complete record is being kept of all work pertaining to the breaker, and no definite maintenance schedule has been formulated as yet. Air-compressor inspection will be governed by actual operating hours.

VIII. Conclusion

We are quite hopeful that this new device will meet operating requirements and reduce materially the time outage for servicing such apparatus. The West Penn Power Company's future breaker purchases will be governed to a large extent by the performance of this unit, and it is hoped that other utilities may benefit and take advantage of this experimental installation.

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Rural Electrification Engineering and Electroagricultural Engineering

M. M. SAMUELS
FELLOW AIEE

THE great interest shown recently by electrical engineers in rural electrification engineering and electroagricultural engineering is demonstrated by the fact that in the October 1942 issue of ELECTRICAL ENGINEERING there appeared a paper which was entitled "New Engineering and a New Industry," presented in December 1941 before the American Society of Agricultural Engineers. The statement made therein that "before 1935 there was no rural electrification engineering," which was misinterpreted by some readers, was not made to discredit the work of anyone in electrifying farms, but referred to the fact that there was no specific branch of engineering that could be called "rural electrification engineering." In fact, we all consider rural electrification engineering as a part of distribution engineering in general, and the latter is likewise a very young branch of engineering. As a matter of fact, very few spoke of "rural electrification." In most of the literature prior to 1935 you will find only the term, "rural line extension." The following statement is from the National Resources Committee report in "Technological Trends and National Policy," 1937, page 284:

"Electric distribution grew as America grew. No one could have possibly predicted the rapid growth of American cities or American industries. During that rapid period of growth, any systematic planning of distribution for several years ahead became out of date on short order. Furthermore, during the rapid growth of the industry, when millions upon millions were spent on generation and transmission, practically all the attention of engineers and manufacturers was concentrated on these two fields. The engineers were so wrapped up in generation and transmission that many of them considered distribution as too lowbrow to merit their attention. Distribution was frequently left to the lineman, purchasing agent, and storekeeper, and many distribution systems grew up to give the impression of crazy quilts, without any apparent logic either in circuit sizes, voltages, or locations, and sizes of transformers."

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M. M. SAMUELS is chief of the technical standards division, Rural Electrification Administration, Department of Agriculture, St. Louis, Mo.

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Distribution engineering really started with the introduction of the a-c network. Rural electrification engineering is a branch of distribution engineering, but the very fine engineering developed for networks, could not be applied to it. Those who had to compute rural circuits had to, and, to a great extent, still have to, use the methods developed by that branch of engineering to which most of the engineering brains of the last 30 years or so has been devoted—transmission engineering. Now, when on a transmission system the short-circuit current, the voltage regulation, and the stability are computed, the results indicate where breakers are needed and what kind, where relays are needed and what kind, where voltage regulators are needed and what kind, where reactors or capacitors are needed and what kind. The equipment can generally be found in a catalogue, and, if you have the money to buy it, even if each breaker costs $130,000, it can be ordered. You can also assume that there will be operators and operating engineers, even specialized engineers who are qualified to operate and maintain the large breakers, the fine relays, the elaborate recording and metering devices, and so forth. When the same method of computation is applied to rural circuits, and when the results are obtained, what do you have? Probably just a fuse, and you hardly have enough money to put in a fuse every place you think there should be one. And in many cases you may not put in a fuse—you will take a chance on getting along without it, because it is practically impossible to co-ordinate fuses as accurately as to co-ordinate relays. And you know that there will be no one but a lineman to operate and maintain. The importance of continuity of service for farming may be far more pronounced than for domestic use. Previously it took two to three weeks to compute the short-circuit current of a rural system, and, after the computation was all done, most of the results could not be used advantageously, since you had to do the best you could with existing equipment. So we first proceeded to reduce the mathematical analysis to existing conditions, with the result that an engineer can now do the job in one day. Second, we were able to show the manufacturer that a good market exists for a good circuit breaker for use on rural distribution circuits. There was only one on the market, but the manufacturer of this breaker had vision and kept improving it to meet the specific requirements of the primary rural circuit, with the result that Rural Electrification Administration systems alone bought over 5,000 such breakers in one year, and practically all systems that have them report that they are satisfied with their performance, because the breakers have saved them many extended interruptions. Other manufacturers have developed small breakers, a few of which are already in operation, but the war stopped further activity. We will need better and cheaper primary circuit breakers, both single-phase and three-phase, with a greater degree of co-ordinating flexibility. Many additional improvements are still needed to give more perfect co-ordination. This is what we call the first chapter of rural electrification engineering. It is by no means complete. (In electrical engineering we are accustomed to being always a few years ahead of the textbook.)

We consider the work done on telephone co-ordination as the second chapter of this specific branch of electrical engineering.

The voltage problem which is now in the process of study, will probably form the third chapter. We have already learned a lot that we did not know before, and some of it, we hope, will soon be ready for presentation to the profession, but it is a long and difficult job, and the analysis no doubt will bring out the need for new equipment. In this whole field of engineering there are not enough operating data for establishing the foundation for all future designs based on Kelvin's idea of balancing fixed charges against variable charges. The systems are too young. But enough data are already available to indicate the need for changes in equipment design. For instance, we already know that rural distribution transformers should have lower core losses. There is hardly any secondary distribution in rural areas; the consumers are so far apart that practically every one must have an individual transformer. Most of the rural systems use purchased energy, and in most cases the cost of energy represents a very prominent item in the total annual charges.

This is in general an entirely different picture as compared to an urban distribution system.

There are innumerable similar items of difference. But what has been said here will be sufficient to stimulate the electrical engineer to devote some time to this new specific branch of electrical engineering and convince the electric-equipment designer that different and new equipment is needed for this field. The market is now large enough to justify these specific studies. For example the following are a few things that manufacturers could devote time to developing: smaller transformer with very low core loss; cheaper, but reliable lightning arresters, based on the fact that the short-circuit current on rural systems is practically never over 1,000 amperes; cheaper meters, more rugged, even perhaps at the sacrifice of a bit of accuracy; simple, cheap, portable instruments to measure ground resistance, without bothering too much about extreme accuracies; insulators that will stay put on the pin and not give radio interference; portable testing instruments that are safe and simple to operate; a simple portable oil tester and filter; new voltage-regulating equipment will no doubt be needed, but the available data are as yet inadequate for definite functional specifications.

There are hundreds of thousands of miles of rural circuits, single-phase, Vee and three-phase, 7,200 volts, all with grounded neutral. Single-phase circuits without any neutral at all are in existence here and there, the earth serving as the return path for the circuit. Each transformer is connected from the phase wire to ground. If there should be a break in the grounding wire or wires any place between the transformer and the ground, there would be practically full voltage across the break. This is indeed dangerous. But we have not heard of any accident resulting from this type of failure. A neutral conductor, which is assumed to be at ground potential, may be more dangerous than a 220-kv line, since adequate precautions always are taken when handling 220 kv. But we must know more about it, and the only way to find out is first to exhaust analytical methods, based on reasonable assumptions that are again based on experience, and then to do a lot of testing. There may be a voltage gradient on the surface of the soil from the pole out, and it will be necessary to establish what that voltage gradient is, because 100 volts may kill a horse. I am not expressing any opinion for or against the use of such circuits; I merely want to emphasize the importance of ground testing on a large scale. Where there is a neutral conductor, it may carry only 30 or 40 per cent of the amperes, the earth carrying the rest. And where there are amperes, there are volts, and here too the voltage gradient should be tested. I know of course that such tests need a voltmeter and not a ground meter, but, if everyone had enough ground meters to establish the ground resistance in advance, the voltage gradients could almost be predetermined by computation. Besides, what are a few ohms of resistance in the life of a young lightning stroke that can jump across half a mile of space with the greatest of ease? Some tests will have to be carried on to determine ground inductance and capacitance. So you see how much engineering there is still to be done on the item of grounding alone before we are ready to say from an engineering viewpoint that we know the characteristics of a rural distribution circuit. This ought to be enough to satisfy those who think that "rural electrification engineering" is as old as Benjamin Franklin.

For supplying electric energy to farms in the less sparsely populated territory, beyond the economy of line extensions, there will be needed small self-contained simple rugged generating units, each to supply one or several farmers. It may be possible that plowed-in underground cable can be used, or that some other new method can be developed for serving a group of farms located in an isolated area.

Constant current primary with constant potential supply and constant potential load, as proposed by Percy H. Thomas and others, deserves serious consideration. Further study may prove its applicability to many conditions in rural areas, and, if it does, new equipment will have to be developed for the purpose. Conditions in the future will no doubt call for underground primary systems, and for these conditions a transformer will be needed which can be put right in the ground without any manholes or boxes. Such a transformer already has been tried out in Canada, but further development will be needed.

During the two years from the middle of 1940 to the corresponding period of 1942, joint development work has continued between the Rural Electrification Administration and the Bell Telephone System to determine the practicability of providing telephone service to rural communities by carrier channels superimposed on power distribution lines. Substantial progress has been made in solving a number of the technical problems encountered. Laboratory models have been made of apparatus which would be required at subscribers' locations and telephone central offices to render this service. Preliminary models also have been made of the apparatus which must be added to the power line, not only at the points where the connections are made to the subscribers' stations and the telephone central offices, but also at other points, in order to provide a satisfactory communication channel.

Considerable work remains to develop the apparatus into good commercial form and to determine from a field trial the answers to the many operating problems which would be encountered in rendering a service of this type. The status of the work recently has been reviewed jointly by the Bell Telephone System and the Rural Electrification Administration, and a decision reached that the work should be suspended for the duration of the war. This helps to meet the present need for concentrating on the war all possible resources, including technical men, critical materials, and manufacturing effort.

Problems of radio interference also occur in rural areas. A reasonably good locator has been developed by Rural Electrification Administration engineers in co-operation with a manufacturer. Several hundred such instruments are now being used with reasonably good results, but improvements are needed. As "telephone interference" was changed to "telephone co-ordination" by co-operative efforts of utility engineers and telephone engineers, so should "radio interference" be changed into "radio co-ordination" by co-operative efforts of the engineers of the electric utilities, the broadcasting companies, and the radio manufacturers.

So you see: The rural circuit is not just a pole, a guy, a little insulator, a little transformer, and a little fuse. It calls for the most painstaking engineering analysis. And when I speak of engineering, I will repeat that anything not based on a solid foundation of physics and mathematics is not engineering.

We now come to electroagricultural engineering. When the statement was made that there was no electroagriculture, it was not meant that no one ever used electricity on the farm. And when it was said that there was no electroagricultural engineering, it did not mean that no engineer ever tried to apply engineering to the use of electricity for farming. Again, it was meant that as yet there is no specific branch of engineering that could be called electroagricultural engineering, and there was no specific industry that could be called electroagricultural industry. As a matter of fact, these things are so new that it is difficult to say now what the

subject of the first chapter of "Electroagricultural Engineering" should be. Even this will have to be developed as we go along. No more will therefore be said here about the engineering possibilities, and the discussion will limit itself to the industrial possibilities. Here we know of some definite needs, and this is addressed primarily to progressive American manufacturers who look ahead, find out what will be required, and proceed to build it and put it on the market.

Electroagricultural engineering is closely associated with rural electrification engineering, because, for example, the grounding problem is probably more important in connection with the fire hazard on the farm than in the city. A faulty ground may cause a fire, and, when a fire starts on the farm, the results are frequently disastrous. A simple cheap ground meter, suitable for the convenient use of every electrician, should be developed. Incidentally, the study of lightning protection of farm buildings and perhaps the development of more competent equipment for this purpose likewise invite some activity on the part of the electrical manufacturers.

While we are on the subject of hazards, we may as well consider the electric fence which is important in wartime, because less critical material may be used. The diversity of the types of control on the market is so great as to be bewildering, and many of the types are definitely hazardous. A committee of the National Electrical Safety Code has been engaged in the study of this subject, but, before quantity production is possible, some work by an AIEE committee and a National Electrical Manufacturers Association committee will no doubt be in order.

When large-scale rural electrification started, all efforts were concentrated on bringing into the farm the minimum amount of civilized comfort such as electric lights, radio, a flat iron, a water pump, a washing machine, perhaps a hot water heater, and here and there an electric range. This was as it should have been. The activity should continue, and improvements should be introduced. Illuminating engineers should study the problem of lighting for the farm, the farm home, the farmyard, the barn, and so forth, and the specific requirements of the circuit. This should possibly be made a project by the Illuminating Engineering Society. Lighting problems on the farm are different and call for different treatment.

An important item of comfort to which manufacturers should devote their attention is the development of a small, cheap, but very reliable water pump, in order to make it possible to bring running water into the poorest farm home. I consider this to be as important as the electric light. Public health authorities are unanimous in their opinion that running water in every home would reduce sickness in the countryside.

Recently there has come about a realization that every effort should be made to develop equipment to make it possible for the farmer who has electricity to use that electricity for real farming, to get more revenue out of his farm, to produce more or better food, to preserve food, and to make it unnecessary to let good food go to waste. This is real electroagricultural engineering. As was brought out in the paper previously referred to, some wonderful work has been done along this line by men of science in the colleges and in other laboratories, but it has not been possible as yet to make the result of their labor available to all the farmers in the country, because there is as yet no specific industry which can manufacture the items as quantity production. There is already some evidence of the beginning of such an industry. What already has been done only helps to demonstrate what we may expect in the future when a real electroagricultural industry is established, using quantity production methods for making low-cost but reliable equipment that the small farmer can use to get a little more revenue out of the electricity that he already has or will have. Most of the items already on the market are too expensive for the small farmer. They are intended for the more prosperous farmer, and our main interest should be to make the small farmer more prosperous.

At various times individuals have endeavored to list the electric equipment and appliances suitable for both the farm and the farm home. Some of these lists exceed the 350 mark. State Agricultural Colleges, the United States Department of Agriculture, and others have been responsible in large measure and have worked exceedingly hard for many years on the research and development of electric applications. It must be said that very few of these have found their way to the farm in large numbers. It is most difficult to get one's teeth into the real meat of these applications, for, although much work has been done, yet little specific information, either on statistics or accomplishments, has been assembled. At first thought this seems strange, because so many of these can be catalogued as income-producing equipment which has been proved profitable to the owner.

The year 1941 was an exceptional year in manufacturing and in the sale of all farm equipment, electric and nonelectric. It exceeded in volume any previous year, and the sales value of it was 36 per cent greater than 1940, and 34 per cent above the high mark set in 1937. Electric farm equipment sold for both the years 1941 and 1940, and the increase in favor in 1940 are shown in Table I.

It will be noted that the electric equipment manufactured and sold in quantity is confined to a few items. Those items assembled and released by the Bureau of the Census include only milking machines, cream separators, milk coolers, domestic pumps, water systems, and brooders. It should be remembered that the figures shown are for years when the sales of these units were exceptionally high. Considering this fact, it is obvious that with 2,337,160 farms electrified we still have a long way to go to reach saturation of this group alone. We will not reach it until we have a specialized industry with quantity production. Even on dairy farms where electricity can be used in so many ways it has been shown on an average that only 10 per cent of the connected load is used for farming operations; the other 90 per cent is used for lighting, household appliances, and water pumping. The former figure is exceedingly low when we think of electric service as being used to increase farm production and income.

An electric motor-driven cream separator will finish the job in half the time that hand work will. With the larger sizes of separator it is now a one-man instead of a two-man job.

Records of 25,000 acres in the state of Oregon which were irrigated show a gross increase of $40 per acre over nonirrigated acres. Although irrigation is practiced in every state of the nation, yet today it is only in its infancy in the humid regions.

Individual farmers report savings up to $100 per year by electric feed grinding, but here too we cannot as yet speak of

Table I. Electric Farm Equipment Sold*

	1941	1940	Increase Number	Increase Per Cent
Milking machines	53,463	33,930	19,533	57.6
Cream separators (hand or power operated)	138,785	105,254	33,531	31.8
Milk coolers	13,143	9,134	4,009	43.8
Domestic pumps and water systems	360,412	267,972	92,440	34.5
Brooders	111,689	91,340	20,349	22.3

* Source: Manufacture and Sale of Farm Equipment. Bureau of the Census, United States Department of Commerce.

general use of electric feed grinders on the farm.

Numerous other activities could be quoted where electricity has been used successfully on the farm. But anyone who has had a chance to see the fine research work being done in the various colleges will at once realize that the surface has not yet been scratched and that manufacturers will find a ready market for many items now in the development stage in the colleges, or in the minds, or the cellars of individual inventors. Until recently there was very little incentive for manufacturers to spend money on the development of new devices for the farm. Such new items are hard to sell and they are expensive to sell. Farmers are far apart from each other, and the very sales effort required for introducing a new item on the farm makes the cost of the article in many cases prohibitive. The REA co-operatives use a group-purchase system, and they can arrange with manufacturers to cover a quantity purchase by one agreement. Since November 1939 the Rural Electrification Administration co-operatives purchased most of their meters under the group-purchase plan, totalling about $4,750,000 to the satisfaction of both the consumers and manufacturers. While all the service transformers for new construction have been furnished by the contractor, the co-operatives used the group-purchase plan for securing close to 25,000 transformers for extensions, totalling nearly $2,500,000. Quite a few other items have been handled successfully through the group-purchase plan, making it unnecessary for the manufacturers to try to sell a new item from house to house.

It is important to realize that whatever is manufactured for the farmer must be low in price, rugged, and simple in operation. Only quantity production can bring about such devices.

It is gratifying to be able to report that there is quite a number of progressive American manufacturers who have been giving this matter their careful attention and have been spending considerable sums of money on development of many devices suitable for quantity production.

One manufacturer developed a self-contained quick freezer and cold-storage unit having a capacity of 20 cubic feet, which means that it will hold about 1,000 pounds of meat, or 500 pounds of fruit or vegetables. It is sufficiently small in dimensions to be accommodated on the back porch of the house, and it is estimated that on a quantity production basis it would cost less than $300. There is no question that there is an enormous market for such an item.

Another manufacturer, to make it possible for the farmer to grind his own whole-wheat flour and cereals, making it unnecessary to ship his wheat to the factory and then get it back again in the form of flour, developed a small kitchen-type flour mill weighing only 25 pounds and able to grind 20 to 40 pounds of flour per hour. The cost of this little mill based on quantity production will not exceed $25, and it is hoped that eventually it will have an attachment so that the standard makes of mixer attachments in the kitchen can be attached to the mill, thus eliminating the necessity of buying a mixer. But this idea, along with the freezer, had to be put to sleep temporarily on account of the war.

Dehydration is another very important item. We know, of course, that there is a great deal of commercial dehydration going on in this country and that dehydration made it possible to send enormous quantities of food abroad which otherwise could not have been sent. But two problems on the farm are as yet unsolved.

1. Everyone who has traveled through the country knows that enormous quantities of apples, peaches, and some vegetables go to waste, because the farmer cannot afford to harvest them.

2. It should be made possible for the farmer to dehydrate such fruits and vegetables for his own use.

A small kitchen type dehydrator would solve these problems. One progressive manufacturer developed a small dehydrator weighing less than 100 pounds and being 28 by 20 by 23 inches in dimensions. This little dehydrator does not call for special wiring, because the consumption is so low that it can be attached to the house circuit. It can produce in 12 hours four pounds of dehydrated apples from 25 pounds of apples, and consumes only 2.4 kilowatt-hours per pound of dehydrated apples. This item is likewise kept in abeyance because of the war.

These are outstanding examples of the difference between homemade equipment and manufactured equipment. Numerous types of dehydrators have been designed by various schools, and the designs have been sent to the farmers with the advice that they produce those dehydrators themselves. It is not necessary to dwell upon the fact that during this critical wartime man power on the farm is now very scarce and that the farmer has no time to devote to the production of mechanical equipment, but even in peacetime very few farmers would be interested in producing such a device if a better commercial product were available at a reasonable price. Besides, all of the designs for homemade equipment show electricity consumption much greater than that of the one proposed by the manufacturer. Some of the homemade dehydrators require as much as 5 kilowatt-hours per pound of dried apples as against the 2.4 kilowatt-hours that the manufactured equipment would require. There is no question that there is a market for hundreds of thousands of such small dehydrators if produced in quantity, of high quality, and at a low price. The estimated price of this particular dehydrator is about $36, based on a quantity of 5,000. But other manufacturers likewise are working on the development of a small dehydrator, and no doubt when the market opens up the price will be lower.

The matter of chicken brooders is something for manufacturers as well as for an AIEE committee to study. Here too the number of designs is so great as to be bewildering and make it difficult for a farmer to select the type of brooder he should buy, to say nothing of making one himself. It should be possible now to crystallize a small number of standard designs that will meet all the requirements of the various agricultural schools and individual farmers and prepare some definite specifications under the auspices of the American Standards Association. This and only this will make it possible for reputable manufacturers to go into quantity production of brooders and for the farmers to get the best brooders for the lowest price.

Some studies have been made on soil treatment by application of electricity, and there is a beginning of promising results. In one case, for instance, electric soil treatment eliminated entirely the wild morning glory (bindweed). In another instance a better quality flax was produced after the soil was treated with an electric process. This, too, should be studied by manufacturers with a view toward producing eventually standardized equipment for electric soil treatment. Experiments have been carried on to use electric light for the control of the European corn borer. You know, of course, what a pest the corn borer has been. I have been told that in some parts of the corn belt farmers have stopped raising sweet corn solely on account of the corn borer. These experiments likewise had to stop, because the one who was outstanding in this work is now in the Army, but the work should be picked up again, and standard equipment should be developed that could be sold to every farmer who raises corn.

Some research men have been working on the development of a small pasteurizer

Transmission-Line and System Problems in Supplying Large Electric-Arc Furnaces During Wartime

B. M. JONES
FELLOW AIEE

ELECTRIC-ARC furnaces are contributing materially to the war effort, and a great number of them, small, medium, and large, have been installed recently, and more are being installed all over the country. These furnaces inherently produce a violently fluctuating load with widely different values in the several phases during the early part of the heat, referred to in the trade as "the meltdown period," and the electric lines and systems to handle such loads must be carefully designed and installed so as to prevent such swinging loads from affecting adversely the system and other critical loads, particularly the lighting, and at the same time to provide sufficient capacity and voltage for satisfactory furnace operation. Also, such lines must be so arranged and connected into the system that the minimum of copper will be utilized—most important now.

This article will discuss some of the basic data necessary to have at hand in the solution of the problem of connecting such loads to an electric transmission system, together with the actual solutions brought about by the installation of 20 furnaces, medium and large, in ten plants of the Duquesne Light Company system.

Briefly, there are five major problems involved, and the last is the most important in time of war:

1. To provide adequate line and/or step-down transformer capacity to carry the heating load that the furnace imposes thereon.

2. Similarly, to provide adequate line capacity to handle the violent one- and three-phase load swings and deliver usable voltage.

3. To connect such line extensions into the system at a suitable location to avoid: (*a*) subjecting other customers to objectionable flicker, and (*b*) causing objectionable operation of various equipment on the system, such as induction-feeder voltage regulators, governing equipment, tie-line controls, rotating equipment, and so forth. (In time of war, such limitations have been stretched of necessity and in some instances waived entirely.)

4. To reinforce the system and/or lines as required.

5. To use the absolute minimum of copper and other critical materials.

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B. M. JONES is division planning engineer, systems planning and development department, Duquesne Light Company, Pittsburgh, Pa.

Nature of Furnace Loads

The load of a three-phase electric-arc furnace is of a violently fluctuating nature, as is shown in Figure 2, which is the oscillographic record of the amperes in each of the three phases of the 5,000-kva furnace transformer listed as item 7 in Table I. The section at the left was taken during the early meltdown period and, as can be seen, the arc strikes and goes out repeatedly with only a few cycles intermission, and this continues for an appreciable length of time, 20 to 30 minutes or more. The middle section was taken after the furnace had been in operation for a while and was approaching the end of the meltdown period. Note that the arc does not go out so often nor remain out so long, although in this oscillogram the middle phase does fluctuate quite widely. The section at the right was taken during the refining period and is approximately a balanced load, and during this time the arc does not go out.

There is no system problem in carrying the load during the refining period, but there is a very real problem in providing facilities to carry loads of this nature with reasonable expenditures and with minimum use of critical materials.

Figure 3 shows the frequency of instantaneous three-phase reactive megavolt-ampere swings for various-size furnaces, and in several tests made it has been disclosed that the highest swing occurs only once in a six-hour heat, and that the next ten high swings are less than 80 per cent of this one value. This case was on a 10,000-kva furnace transformer, and we have data on larger units which approximately bear this out. The objectionable zones of voltage flicker previously referred to are more likely to be in the latter range than for the one or two infrequent higher swings.

A study of Figure 3 will show the steepness of the curve for the infrequent swings, and the lower swings, or more infrequent ones, will probably not require so stiff a system and hence probably will require less material. We doubt the advisability of tooling up for the one or two maximum swings during a heat of even one or two hours, let alone for the one large swing occurring in a six-hour heat during wartime.

The larger swings produced by several furnaces in simultaneous operation in one plant occur very infrequently—in fact our investigation discloses that they are of less frequent occurrence than the one high swing of one furnace operating alone.

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for the small farm that could be had at low cost, and the prospects are very promising. This work should have the attention of electrical manufacturers. It should be made possible for the small farmer to pasteurize his milk and sell it in the community.

The possibility of a storage-battery-driven electric tractor has not yet been exhausted. Some experiments were made prior to the depression but were dropped. It is difficult to predict whether or not such a tractor would be a success. It is possible that if the cost of energy for charging the batteries at night is very low a market would be opened for small tractors to be used by hundreds of thousands of small farmers.

There is a decided need for simplification of motor starters for medium-sized motors for farm use and also for a reduction in the price of the starters.

When the war is over a great deal will be known about high frequencies that is not known now, and it is possible that high frequencies ranging from audio frequencies to ultrahigh frequencies may have a great many applications on the farm. It may be possible to apply high frequency for soil treatment, and supersonic waves may possibly be applicable for extermination of pests. This subject calls for much more study by electrical engineers.

Reference

1. NEW ENGINEERING AND A NEW INDUSTRY, M. M. Samuels. ELECTRICAL ENGINEERING, volume 61, October 1942, pages 517-20.

Table I. Transmission Supply Lines, Short-Circuit and Voltage Flicker for 20 Furnaces From 1,500 to 15,000 Kva in Ten Plants in Duquesne Light Company System

Item No.	Furnace Transformer Data: Quantity	Largest Transformer (Kva)	Supplemental Reactance Used	Supply-Line Data: Voltage (Kv)	From Network or Separate Line	Figure No.	At Customer's Substation: At Incoming Bus: Three-Phase Short-Circuit (Kva)	Reactance in Ohms: Three-Phase	Single-Phase	At High-Voltage Furnace Bus (Reactance in Ohms—Single-Phase)	Volts Regulation on 115-Volt Base and Based on Instantaneously Established Single-Phase Swing: At Customer's Substation: At Incoming Bus	At Furnace High-Voltage Bus	At Nearest Critical Station Bus
1	3	15,000	No	68	Network	6-A	1,179,000	3.925	7.85	24.72*	1.53	4.80	1.37
2	2	10,000	Yes	68	Network	6-B	749,000	6.18	12.36	37.02*	2.60	5.98	0.98
3	4	10,000	No	68	Separate**	6-D	304,000	15.22	30.44	46.64*	4.92	7.55	1.23
4	1	7,500	Yes	23	Network†	5-B	439,000	1.205	2.41	2.41	2.99	2.99	1.97
5	1	7,500	Yes	23	Separate	None	132,000	4.01	8.02	8.02	9.94	9.94	2.75
6	2	6,000	Yes	68	Separate	6-C	330,000	14.02	28.04	83.6*	3.52	10.50	1.78
7	1	5,000	Yes	23	Network†	5-C	251,000	2.11	4.22	4.22	4.12	4.12	3.74
8	2	4,000	Yes	23	Separate	5-D	103,000	5.12	10.24	10.24	8.70	8.70	1.76
9	1	3,000	Yes	23	Network	5-A	319,500	1.656	3.31	3.31	2.34	2.34	1.87
10	3	3,000	Yes	11.5	Separate (see text)	4-A	364,000	0.363	0.726	0.726	2.02	2.02	1.48

* Includes intermediate transformation between incoming supply lines and the high-voltage furnace bus.

† A separate isolated 22-kv line can be made available by the opening of a remotely controlled oil circuit breaker at the customer's plant if necessary when the furnace loads are swinging.

** A separate line or lines required for line loading and not for furnace load fluctuation.

Pure reactive used for overhead lines and 80 per cent of impedance for cables. All jobs are overhead lines, except item 10 which is all cable.

In specific tests on an installation of four 10,000-kva furnaces in the same plant, the increase of the maximum swings of two furnaces when operating simultaneously melting down over one alone was about 20 to 25 per cent. Similarly for the three similar furnaces over two, the increase was seven to ten per cent additional.

These records of Figure 3 were obtained from high-speed graphic meter charts at three inches or six inches per minute, and it is recognized that there is some error in these charts, because of the fact that the swings take place so rapidly the instrument cannot follow them accurately. The oscillograph is the proper measuring device to use to obtain such records, but it is believed that these curves are indicative of the general relation.

It is also recognized that the lamp flicker, the source of complaints, is the result of single-phase swings, but the single-phase data were not available. However, it is believed that the three-phase data will be indicative of the general relation between single-phase swings of different-size furnaces.

The swings are affected very materially by type of scrap and by how the furnace is operated. For instance, recently we have tested a large furnace which was charged with light scrap loosely packed in, with the resultant swing being about half or two thirds of those on similar furnaces when charged with heavy scrap carefully packed in. Also, the amount of supplemental reactance (the tap connection of the reactor) in use in the furnace transformer has a very material bearing on the magnitude of the swings. Therefore, caution is urged in attempting to use these curves as a criterion of furnace performance, but they will be helpful as a guide.

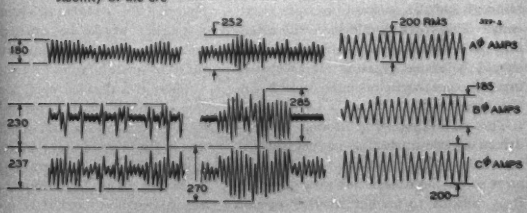
The number and sizes of furnaces and the conditions of the tests for the curves are given below:

Curve A. Four 25-ton 10,000-kva furnaces and one 36-inch slabbing mill supplied by a 37,500-kva 66/11-kv bank, in normal operation. Details are not available. The mill load is relatively steady and has a small effect on the shape of this curve. New furnaces of this size would probably have a normal rating of 35 tons. Data for curves *B*, *D*, *E*, and *F* were taken on same installation. Curve *A* was plotted from 3½ hours high-speed meter record over several days in July 1942 and measured at the 66-kv bus at the power station. The customer is supplied by a 4/0 66-kv line 14 miles long.

Figure 1 (left). A typical large modern three-phase electric furnace "pouring"

Figure 2 (below). Oscillograms of the three-phase currents of 5,000-kva furnace during early meltdown, later in the meltdown, and during refining

Note the different degree of stability of the arc



Curve B. One 25-ton 10,000-kva furnace supplied by a 37,500-kva 66/11-kv bank. This is an estimated curve at ten per cent above curve *D*.

Curve C. One 50-ton 12,000-kva furnace supplied at 24 kv by means of a 4/0 line one-half mile long from a very large step-down bank. Curve plotted from five hours ten minutes high-speed meter record for a full heat in January 1940. Heavy scrap used.

Curve D. One 25-ton 10,000-kva furnace supplied by a 9,375-kva 66/11-kv bank. Curve plotted from high-speed charts covering a six-hour run for one full heat in April 1940. Heavy scrap used.

Curve E. Two 25-ton 10,000-kva furnaces, each supplied by one 9,375-kva 66/11-kv bank. Curve plotted from a six-hour high-speed meter record in September 1940, with simultaneous melting down of the two furnaces for 1¾ hours of this time. Heavy scrap used.

Curve F. Four 25-ton 10,000-kva furnaces supplied by a 37,500-kva 66/11-kv bank with three furnaces melting down simultaneously and one refining. Curve plotted from 40 minute high-speed meter record in September 1941. Other spot tests show infrequent swings higher than these, even higher than for two furnaces, curve *E*. Low values—much higher expected.

Curve G. One 15-ton 7,500-kva furnace supplied by a two-mile 4/0 22-kv line which in turn is supplied from a 60,000-kva 66/22-kv bank. Curve plotted from two hours 15 minutes high-speed meter record of the early part of a heat in April 1942. Light scrap and restricted operation.

Curve H. Two 7.5-ton 6,000-kva furnaces supplied by one 9,375-kva 66/11-kv bank. Curve plotted from six hours 50 minutes high-speed meter record in August 1942. Light scrap and reduced operation.

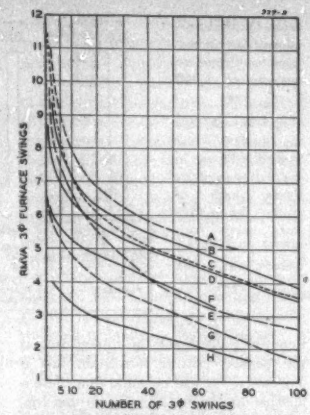


Figure 3. Frequency of instantaneous three-phase reactive-megavolt-ampere swings for various size furnaces, individually and in groups

A=4–10,000 kva and mill
B=1–10,000 kva
C=1–12,000 kva
D=1–10,000 kva
E=2–10,000 kva
F=4–10,000 kva
G=1– 7,500 kva
H=2– 6,000 kva

Voltage Fluctuation Limits of Duquesne Light Company

We have peacetime voltage-fluctuation limits of 1.5 and 2.0 volts on the 22-kv and 66-kv systems respectively for fluctuating loads of arc-furnace characteristics, which we used prior to the war as a guide in connecting furnace loads, but these limits have been waived of course since the war started. The voltage flicker limits are more severe for the 66-kv system in certain zones of frequency of occurrence than for other parts of the system, for the reason that the cost to provide corrective measures would be greater than on other parts of the system. Of course, the same perceptible and objectionable zone will exist, but more consumers would be exposed to the voltage flicker, and hence presumably more complaints would result.

By adhering to these limits before the war, we encountered very little objection to voltage flicker from consumers, and the few have been mainly the result of welder installations which were greatly exceeding these limits, rather than furnace installations. In many cases we now permit fluctuations considerably in excess of these values, even though we realize that they are definitely perceptible and, in certain cases, may become objectionable.

To some, these limits may appear to be rather severe, but our successful experience in applying them, we believe, justifies their retention after the war. We of course exercise judgment based upon experience and stretch these limits in certain cases, even in peacetime. We were considering revising these limits to be more lenient, even before the war, and our experience during wartime will be of considerable use to us in the next revision.

The matter of perception of and objection to voltage flicker is not, in my opinion, subject to exact scientific determination. Much research work has been done on this, and while some consumers will object strenuously to voltage flicker, others would not even be conscious of the same flicker. Some of the best work done on this is covered in a pamphlet entitled "The Visual Perception and Tolerance of Flicker," a report of the subcommittee for project 10, Utilities Co-ordinated Research, Inc., 1937, which, I believe, is available at a reasonable price.

System Regulation

The voltage flicker at the nearest adjacent substation is generally not the governing factor, for this nearest station may be an industrial consumer where considerable flicker can be permitted without encountering objections, whereas a distribution substation supplying lighting may be farther away (electrically) from the furnace than the industrial substation, and yet objectionable flicker may be rendered to the lighting consumers. However, the industrial consumer's substation may be the governing factor, for there may be critical drafting-room lighting requirements or fluorescent lighting in certain processes, or other manufacturing requirements.

The instantaneous swings lasting less than a second (of cycles duration or less) occur more frequently than swings lasting several seconds, the latter reaching the maximum value in several steps, each of which is generally smaller than the maximum swings lasting less than a second. The swings of the shorter duration being more frequent are the final criterion insofar as flicker is concerned, but there is, of course, more total regulation for the swings lasting several seconds, because they reach a higher value.

However, our experience has been, and that of some other power companies bears this out, that the regulation problems of loads lasting several seconds is not of any serious concern, for if you tool up for the instantaneous swings, the condition occurring less frequently causes no complaint.

11-, 22-, and 66-Kv Line Connections for Electric-Arc Furnaces From 1,500 Kva to 15,000 Kva

Table I shows data on the transmission supply lines, short-circuit kilovolt-amperes, and voltage flicker or regulation for 20 furnaces from 1,500 kva to 15,000 kva in ten plants on the Duquesne Light Company system, and there is also included the impedance in ohms, both one-phase and three-phase, at apropos locations.

In three instances, the peacetime limitations are or will be exceeded, and from none of these are complaints being encountered, nor are any expected. Also, it is believed that no serious complaints

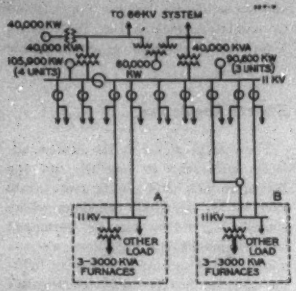


Figure 4(left). Eleven-kilovolt line connections for electric-arc furnaces of 3,000 kva

Larger furnaces can be supplied by the methods shown in the *A* diagram of this figure, with of course the supply lines being reinforced to carry the heating load of the furnace

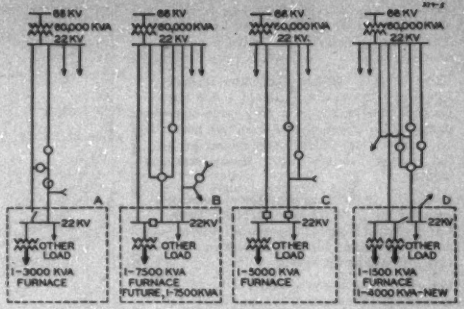


Figure 5. Twenty-two-kilovolt line connections for electric-arc furnaces of 1,500 kva to 7,500 kva

Sixty-six-kilovolt transmission system with 624,000-kw generating capacity

during wartime will be encountered from flickers considerably in excess of those shown. Further, it is felt that values appreciably in excess of those shown would not interfere with war production.

Item 7 in Table I will be much less severe when isolated temporarily as described in the note beneath the table.

11-Kv Line Connections for 3,000-Kva Electric-Arc Furnaces

Figure 4 shows two methods of 11-kv line connections for three 3,000-kva furnaces, and the data for sketch *A* of this figure are given in Table I as item 10. The two lines of 500,000-circular-mil cable, 1.5 miles long, feeding this furnace substation, connect to separate busses at the power station which are supplied through reactors from the main generating source, and the feeder bus also supplies other distribution substations as indicated by the short lines with arrows. The voltage flicker of 1.48 volts at one of these two substations is the limiting point and is less at the 11-kv feeder bus in the power station, that is, 0.44 volt.

The wartime cable rearrangement involved a very small amount of copper.

The corresponding voltage regulation at the power-station feeder bus for sketch *B* of this figure is 0.44 volt and is 1.72 volts at the nearest industrial consumer.

At the time of preparing this paper, one furnace only is in service.

22-Kv Line Connections for 1,500-Kva to 7,500-Kva Electric-Arc Furnaces

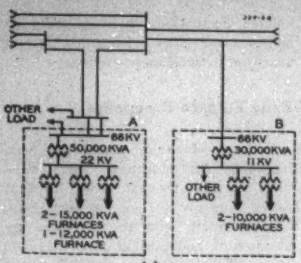
The larger number of our furnaces are connected to the 22-kv transmission network by the lines in that vicinity rather than by an exclusive line from a major transmission stepdown substation. Some of them, however, are connected to a separate exclusive line, items 5 and 8 in Table I being in this category.

Figure 5 shows several recent installations. Diagram *A* of this figure covers the supply to a 3,000-kva furnace and is item 9 in Table I, and the voltage drop at the nearest critical substation bus is 1.87 volts. It will be noted that there is another line normally open to this consumer, and, when one is operating on this second line with the first open, the voltage drop at the nearest critical substation bus will be somewhat greater. The 22-kv lines are 4/0, and the wartime line rearrangements and the waiving of peacetime flicker limits resulted in installing only 800 feet of 4/0 line.

Diagram *B* of Figure 5 covers the supply to one 7,500-kva furnace now in service and another one authorized and is item 4 in Table I. The drop at the nearest critical substation is 1.97 volts. There are other substation busses getting larger voltage drops than this, but they are industrial consumers supplied at 22 kv and are not so critical. The exclusive line is 4/0 and is two miles long. Careful study developed a scheme of handling this furnace load, without any line copper being used, by rearranging the consumer's 22-kv bus in order to isolate the direct line at times of meltdown.

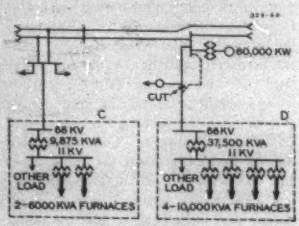
Diagram *C* of Figure 5 covers the supply to a 5,000-kva furnace which has been in service for a number of years and which creates much wider fluctuations than other furnaces of this size and larger. This is item 7 in Table I. The voltage drop on the basis of normal single-phase swings expected from such a size transformer at the nearest critical substation bus is 3.74 volts, and at the 22-kv bus of the nearest major-ring stepdown substation is 2.17 volts. With the abnormal swings that this furnace transformer produces at times because of its unusual impedance characteristics, these values are exceeded, and certain remedial steps were taken shortly after this furnace was installed. These remedial measures consisted of changing the adjustment in voltage-regulator relays on the induction feeder regulators in the nearby substations to permit the higher short-time voltage swings to filter through the relay without causing the regulator to operate, and placing a little time delay in the initiating devices of these induction feeder regulators; also, certain 22-kv line rearrangements were made in this vicinity at that time, and remote control facilities were added to the incoming line breakers at this substation, so that one of them could be opened and the furnace operated on a direct 4/0 line approximately three miles long from the stepdown transmission substation. These remedial measures have eliminated completely the complaints that we received in copious quantities when this furnace was first placed in service. Actually, the consumer is now operating radially on one direct line from the major stepdown transmission substation during the meltdown periods.

Diagram *D* of Figure 5 covers the supply to an old 1,500-kva furnace and a new 4,000-kva furnace. The latter furnace required a separate radial line. The final line arrangement in the district is shown. Pertinent electrical data are covered in item 8, Table I. The old furnace and the mill load were supplied by the 22-kv network in that vicinity, and the old furnace did cause an undesirable but not intolerable voltage condition. For this reason it was reconnected on the new radial line together with the new 4,000-kva furnace. With the furnaces supplied by an exclusive line (1/0 copper and six miles long), the voltage drop at the nearest critical substation bus is 1.76 volts. A bus tie switch is installed between the furnace bus and the bus which is supplied from the network. This was done in order to permit the furnaces to be operated at reduced voltage in case the radial line is out of service for an extended



(A)

A. Sixty-six-kilovolt transmission system with 624,000-kw generating capacity



(B)

B. Sixty-six-kilovolt transmission system with 624,000-kw generating capacity

Figure 6. Sixty-six-kilovolt line connections for electric-arc furnaces of 6,000 kva to 15,000 kva

period. If normal furnace voltages are used under this condition, the voltage fluctuation at the nearest critical bus in the network is intolerable.

A *new* exclusive furnace line would have required a large amount of critical materials. By consolidating loads in two districts into one district, a 22-kv line was released and extended for service to the furnaces. Actually, 53,000 pounds of copper were saved by the rearrangements as compared with a new exclusive line.

66-Kv Line Connections for 6,000-Kva to 15,000-Kva Electric-Arc Furnaces

The 66-kv method of supply is used for four plants, one of them having the largest furnaces on our system. Figure 6 shows these connections.

Diagram *A* covers the supply for three large furnaces—two 15,000-kva and one 12,000-kva. This is item 1 in Table I. One furnace is in service now, and the others are expected to be in service during the winter of 1942–43. This is an interesting connection, for the mill where the furnaces are located is supplied at 66 kv from a power-company substation approximately 1.0 mile away. A considerable portion of other load of this same consumer is supplied from the power-company bus and from the 66-kv furnace bus in the mill where the furnaces are located, all as shown in this diagram. As a matter of interest there are 60-cycle generators proposed for connection to the consumer's 66-kv lines in one of his mills, and we will operate in parallel with these generators which are scheduled for service sometime in 1943. The two power company 4/0 66-kv lines 0.5 mile in length were installed four years ago for mill load only then, and today for furnaces alone we would supply one line. The voltage drop at the nearest critical substation is estimated to be 1.37 volts.

Diagram *B* covers the supply for two 10,000-kva furnaces which are expected to be in service early in 1943. This is item 2 in Table I. The "other load" shown in this diagram is a very small part of the load and is merely for handling facilities and shop lighting, and this is purely an electric-furnace plant for producing steel ingots and will in no way fabricate or process them. This was a fortunate location as the 1/0 line extension from the main 66-kv transmission will be only approximately 1.5 miles. The voltage drop at the nearest critical substation is estimated to be 0.98 volt.

Diagram *C* covers the supply for two 6,000-kva furnaces. One of these was in service in 1941, and the other early in 1942. This is item 6 in Table I. This location was not so fortunate since it required 4.0 miles of 4/0 66-kv line added to 4.0 miles of existing 4/0 line from the transmission substation bus to reach this. The voltage drop at the nearest critical substation is 1.78 volts.

Diagram *D* is an interesting installation and supplies four 10,000-kva furnaces over a 4/0 line about 14 miles long. This is item 3 in Table I. This furnace load began with one 10,000-kva furnace connected at the point marked "cut" and supplied from the transmission network in this vicinity by a nine-mile line extension. Within five months a second furnace was installed and was carried without any line reinforcing. Then, about a year later two more 10,000-kva furnaces were installed, and this necessitated cutting the line, at the point shown in diagram *D*, from the network and extending it back to a stiffer source, which is now a generating-station bus but which at that time was at a point on the 66-kv transmission. The voltage drop at the power station 66-kv bus for the present connection is 1.23 volts. At the time of the initial installation the voltage drop at the nearest substation was higher, but no complaints were received.

Kilowatt Demand and Kilowatt-Hours

Table II gives these data for various sizes of furnaces, which data are incomplete, for in some cases the kilowatts and kilowatt-hours are totaled along with other mill load, and the remainder are on other systems, and only partial data are available to the writer. Experience and skill, together with other factors listed below, will affect the electrical performance very materially, as well as the tonnage output.

Production of steel by electric melting, and the electrical requirements—kilowatts, kilowatt-hours, and load swings—are

Table II. Furnace Size, Kilowatt Demand- and Kilowatt-Hours Per Ton

Partial List for Representative Sizes

Item No. in Table I	Furnace Size Net Short Tons	Transformer Rating—40 C (Kilovolt-Amperes)	Kilowatt-Hours Per Net Short Ton Produced	Kilowatt Demand 15-Minute Integration
*		1,500		1,350
10*	3.0	2,500		2,300
9*		3,000		2,200
	6.0		827	
8*		4,000		3,630
	10.0		795	
6	10.0	6,000	604	6,240
4	7.5	7,500	608	7,500
	10		723	
3	25	10,000	580	8,400
	25		569	
	30		601	
	35		585	
	35		569	
	50	12,000	523	
	60		556	

* Foundries. All data not available—see text.

governed by many variable factors, some of which are subject to some degree of control; among these important factors are the following:

1. Type and size of scrap.
2. How charged—"packed in," and so forth.
3. Quality of finished production—mild steel, alloy, high grade alloy, and so forth.
4. Skill of furnace crew, particularly that of the turn foreman and melting superintendent.
5. Proper size of transformer.
6. Use of proper transformer taps and control adjustment.
7. Design of entire electric installation—furnace, transformer, wiring, and control, the latter contributing very largely to the success of larger arc furnaces.
8. Charging equipment and general layout.

The nominal tonnage rating of an electric-arc furnace used herein does not indicate necessarily the actual production capacity, for, as previously explained many variable factors affect the production, and this is merely a nominal rating for identification purposes, and actually the tonnage produced may be more. Usually, with the larger furnaces for steel making, the nominal tonnage rating, so-called, indicates the holding capacity of the furnace in net tons, whereas with some of the smaller furnaces in foundries the rating is the net ton produced per hour. One large manufacturer has within the last few years ceased to give his furnaces a rating and now identifies them by a type number.

The experience of a considerable number of plants using electric furnaces over a number of years has disclosed that in some installations the furnace transformer was replaced with a larger transformer, since we had had several such cases on our system—some within the last year. This comes about for such reasons as enlarging the furnace, more tonnage requirements, melting different materials, becoming more skilled in the operation, and so forth.

Other Power Companies' Fluctuation

Different power companies have different requirements for the connection of furnace loads. All of the power companies on which I have data indicate that the frequency of the furnace swings and their magnitude govern the amount of stiffness required in the system at the point of service, for these are the criteria of the flicker which will result in voltage complaints if any are incurred. For instance, one power company requires a short-circuit duty at that spot of 1,000,000 kva for connecting a 10,000-kva electric-arc furnace on the basis of limiting the voltage fluctuation to two per cent, assuming the instantaneous swings to be twice the transformer rating. Another power company feels that the short-circuit duty should be 750,000 kva or greater on the basis of a two-volt flicker on a 120-volt base. Some other power companies have installations in satisfactory operation with five to six per cent voltage swings on the consumer's primary bus, and they feel that 7.5 per cent would also be satisfactory, and they make reference to two per cent limits on the system at critical points.

One large power company claims that its test data disclose single-phase swings from approximately 1,500 kva to 6,500 kva for three-phase electric-arc-furnace transformers varying in size from 1,000 kva to 10,000 kva, with corresponding power-factor variations from approximately 40 to 65 per cent. The Duquesne Light Company test data for several comparable installations check fairly closely with these figures.

All and sundry advise caution in supplying lighting, particularly fluorescent X-ray equipment and other critical apparatus from consumer's primary busses and from lines and/or busses that supply such critical load.

One large power company is fortunate in having most of its heavy industrial load confined to a definite area and has provided a separate bus known as "flicker bus," from which all such loads are supplied. Such a bus can stand much greater voltage fluctuations than one carrying lighting and other critical load. Not many are so fortunately situated.

Early Furnace Experience

Duquesne Light Company has been supplying electric-furnace loads since 1908, and, it is thought, it was the first power company to pick up such load. Even in those days the necessary research work and calculations were made before connecting a furnace to the system, and a trial installation was actually made of the first furnace in the power-station yard, with one engine-driven generator isolated to carry the load for the tests. Subsequently, as a result of these tests, the furnace installation was made in the steel mill and was supplied for a while by an isolated generator and line. As the system grew, the generator and line were tied into the network. This installation was in use in this plant for many years and was scrapped just a few years ago, but other larger furnaces were later installed and have been in use for many years.

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Insulation Testing of Electric Windings

C. M. FOUST
MEMBER AIEE

N. ROHATS
ASSOCIATE AIEE

I. Introduction

THE paper describes a new method for the testing of insulation of windings, the advantages of which are adequate stressing of turn and conductor insulation and certain detection of defects. The new tester consists of a repeating-type surge generator, cathode-ray oscillograph, and synchronously driven switching equipment. The surge generator provides a succession of voltage waves of controlled shape adjusted to give the necessary turn and conductor insulation stresses. The cathode-ray oscillograph is timed to give a stationary image of the repeating surge on the screen. By virtue of the special method of surge application and oscillograph connection, the waves on the screen indicate turn or conductor-insulation defects quickly and certainly.

In high-potential testing, voltages in all parts of a winding should be high enough to result in insulation failure at all points where insulation strength is not adequate to withstand service conditions. To this end, test voltages must be used sufficiently above normal excitation voltages to properly stress conductor insulation and sufficiently rapid in rate of change to stress turn insulation properly. Accordingly, power-frequency voltages, usually two times normal plus 1,000, are used for conductor-to-ground insulation and high-frequency voltages applied directly or by induction are used for turn insulation.

In service, insulation must withstand normal voltage excitation, switching voltages, and other transients such as lightning.[1] Switching surges range below 5.5 times normal but may, as in the case of lightning transients, have high rate-of-change characteristics. Time to crest may be as low as one microsecond. As nearly as practical these service voltage conditions should be reproduced in test.[2-12] The test method described in this paper is directed toward the ends of adequate stressing of all insulation and certain detection of weak spots.

The new method has been used for different types of coils and windings and has been applied to particular advantage in the testing of completed windings of three-phase low-voltage rotating machines. In this case surge voltages are applied alternately to each of two of the terminals of the machine with the oscillograph connected to the third terminal.

Paper 43-59, recommended by the AIEE committee on instruments and measurements for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted November 19, 1942; made available for printing December 22, 1942.

C. M. FOUST and N. ROHATS are both with the general engineering laboratory, General Electric Company, Schenectady, N. Y.

II. Wave Propagation in Machine Windings

Experimental work and practical testing experience on production machine windings have indicated definite improvements in line with the objectives already stated. As very little experimental work has been reported on wave propagation in windings, it seems advisable to include here a few oscillographic records of voltage wave conditions pertinent to the surge performance of machine windings.

A most significant characteristic of these windings from the standpoint of surge mechanism is that capacitance and inductance elements are necessarily well distributed as to physical position and, therefore, have very low over-all capacitive or inductive coupling. In this report the machine winding is the opposite of the transformer where over-all capacitive and inductive couplings are very high. Because of this distribution of capacitance and inductance elements, the electrical mechanism of the machine winding is that of the traveling-wave as contrasted with the standing-wave mechanism of the closely coupled transformer winding. The surge performance of a machine winding is illustrated in Figure 1 which shows voltage wave shapes measured at suitably located tap points along one leg of a three-phase winding of a large rotating machine. The voltage wave applied was unidirectional in polarity with a time to crest of one microsecond and to half-crest on the wave tail of 5.6 microseconds.

In Figure 1 in the left vertical column are shown the tap voltages for the case of the neutral end open. The voltage wave shape applied is at the top with consecutive taps toward the open end in order below. The unidirectional polarity impulse traveling through the winding sets up a standing-wave oscillation at the open end which has a frequency of some 34,000 cycles per second. Voltage amplitude along the winding first decreases, then increases, reaching a value some 20 per cent above that of the applied wave at the line end. The low-amplitude oscillation at the beginning of the neutral end wave is the result of direct coupling across the winding, as soon as the applied wave enters the winding at the line end. The winding time length, as indicated by this displacement, is just under 4.0 microseconds.

In Figure 1, center vertical column, are shown tap voltages for the case of the neutral grounded, through a resistance of 200 ohms equal to the experimentally determined surge impedance. This series of oscillograms shows the voltage wave traveling through the winding without major reflections and with appreciable amplitude attenuation so that the neutral end wave is about 60 per cent of the applied wave. This attenuation is accompanied by some distortion resulting in a slight lengthening of the wave tail. The loss in voltage amplitude is mainly on the sharp front of the wave, and this has the effect of increasing the time to crest from one microsecond at the line end to five microseconds at the neutral end.

In Figure 1, right vertical column, are shown tap voltages for the case of the neutral end directly grounded. In this case the polarity of the reflected voltage wave is reversed, and a frequency of 77,000 cycles or something more than twice the open-ended winding frequency is obtained. The voltage amplitude decreases at each tap point and at the neutral end is, of course, zero across the ground connection.

These oscillograms show the nature of the voltage variations in a rotating machine winding under conditions of applied surges such as are obtainable with switching, lightning, or other circuit variations. Further experimental work has shown that steeper and short-duration waves are attenuated more rapidly, and more sloping and longer-time waves less rapidly. This type of information can be used as a basis for consideration of voltage stresses and detection of weak spots in winding-insulation testing.

III. Winding-Insulation Testing Method

Experimental work was conducted on improvements in winding-insulation testing, particularly as regards across-winding stresses and weak-spot detection in view of the surge mechanism already described. As a result of this work, the circuit arrangement and method of connection derived from the oscillograph electric transient analyzer[2] and shown in Figure

2 was devised. The principal elements involved are the repeating surge generator at the bottom left, a cathode-ray oscillograph at the top right, the time-co-ordinating and beam time-axis circuit at the top left, and a synchronous reversing switch shown at the bottom right, along with a typical wye-connected winding of rotating machine. The surge generator consists of supply transformer 10, charging tube 11, main capacitor 6, and discharge resistance and tube 7 and 5. This circuit provides a capacitor-discharge voltage wave which is applied through a synchronously operated reversing switch 9 to the machine windings 12 and 13 under test. Time-co-ordinating circuit 1, 2, 3, and 4 supplies time-axis voltage for the cathode-ray oscillograph and operates the surge generator once for each cycle of power-supply frequency, which results in a stationary image of the fault-indicating wave on the oscillograph screen. For practical testing purposes, this equipment is mounted in a cabinet as shown in Figure 3 with the oscillograph at the top and all controls below.

In detail the whole circuit operates as described in the following paragraphs.

The peaking transformer 1 trips the sweep thyratron 2 when its plate is on the crest of the positive half-cycle, thereby

Figure 1. Wave propagation in machine windings

Applied line surge voltage at top. Neutral surge voltages at bottom
Left—Terminus open
Center—Terminus grounded through surge impedance
Right—Terminus grounded directly

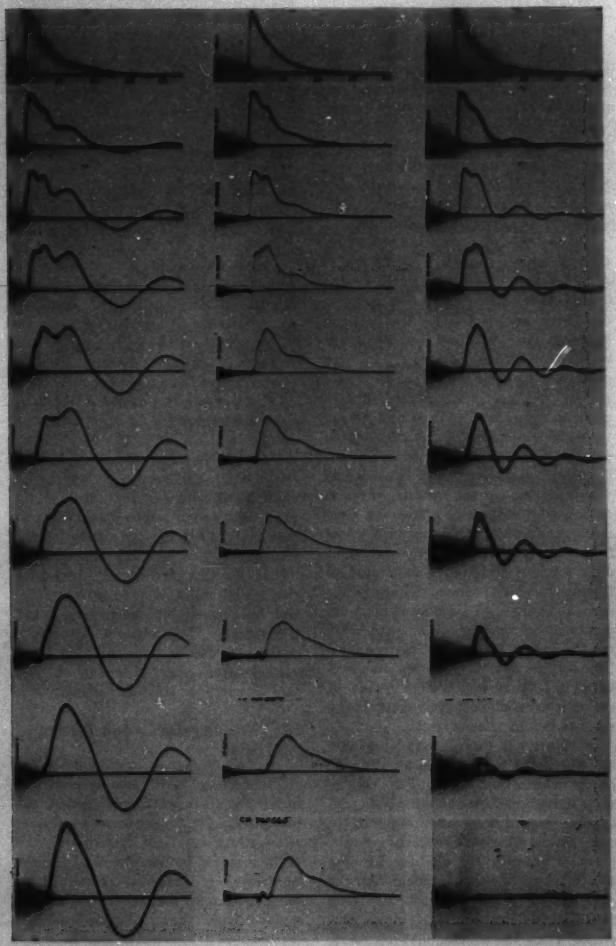


Figure 2. Schematic diagram of winding-insulation tester

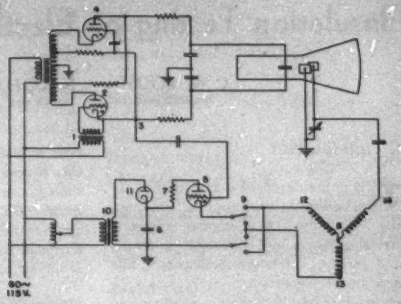
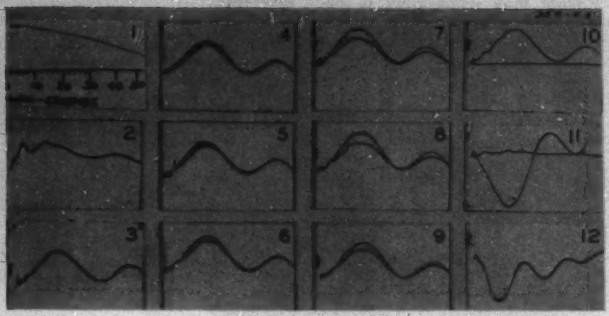
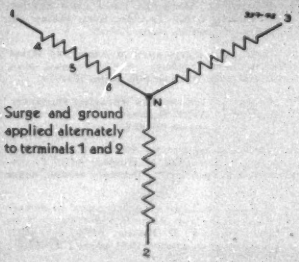


Figure 3. Winding-insulation tester, 10 kv





Record	Fault	Location	Oscillograph
1	None		1
2	None		N
3	None		3
4	One turn short circuit	4	3
5	One turn short circuit	5	3
6	One turn short circuit	6	3
7	One coil short circuit	4	3
8	One coil short circuit	5	3
9	One coil short circuit	6	3
10	Ground	1	3
11	Ground	5	3
12	Ground	N	3

Figure 4. Winding-insulation tester records, single winding

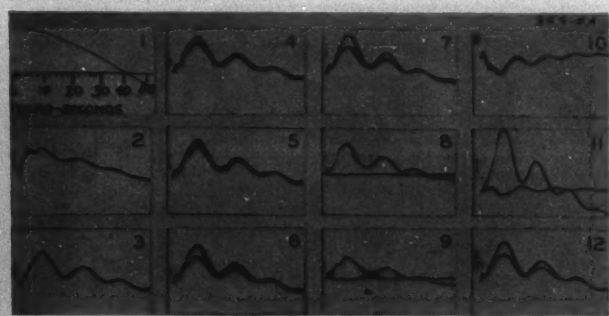
applying a positive impulse to point 3. This positive impulse, in addition to providing one-half the sweep voltage, also trips the tube 4 (which gives the negative half of the sweep), and the large thyratron 5. Tripping of 5 discharges capacitance 6 through resistance 7 into the test winding 8 by way of the synchronous reversing switch 9. Capacitance 6 was charged on the previous half-cycle from transformer 10 through rectifier 11.

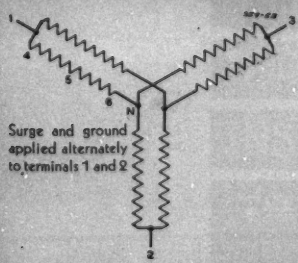
The synchronous switch acts to send alternate surges in opposite directions through the winding 8 between terminals 12 and 13. Terminal 14 is connected through a capacitance voltage divider to the oscillograph deflection plates. The wave shape shown by the oscillograph is, therefore, a resultant of the voltage at the neutral and the voltage induced in the phase to which it is connected.

If the winding is perfectly symmetrical, the wave at the neutral and on the oscillograph will be the same for either direction of surge travel, so that a single standing wave will be shown on the oscillograph screen. If the symmetry is disturbed by a shorted turn or coil, in legs 12 or 13, a ground or improper connection, the two directions of surge travel will give different results and, consequently, two waves of different shape on the screen. Experience has shown that this connection arrangement is extremely sensitive to winding defects and that, to a considerable extent, the relative shapes and amplitudes of the two waves can be used to indicate the nature of the defect.

IV. Specimen Winding-Insulation Tester Records

The oscillograms of Figure 4 show winding-insulation tester performance on a three-phase rotating machine winding. The tester circuit was arranged to give a voltage wave of (1 x 40) microsecond shape. This wave, shown at 1, was recorded by connecting the oscillograph deflection circuit to the impulse input terminal 1 in the diagram. Oscillogram 2 is the wave shape at the neutral of the motor winding obtained by connecting the oscillograph deflection at the motor neutral or point *N* on the diagram. It will be noted that the wave front at the neutral is considerably more sloping than the applied wave of 1, requiring some six microseconds to crest value. Only one trace is shown, indicating identical wave shapes, whether the wave is applied at 1 with 2 grounded, or applied at 2 with 1 grounded. Oscillogram 3 of Figure 4 shows the wave shape at the end of winding 3 with the characteristic standing-wave voltage oscillation agreeing with oscillogram of Figure 1 at the bottom of the left-hand column. Oscillogram 3 also shows only one wave, thereby indicating symmetrical conditions in phases 1 and 2. For oscillograms 4 through 12, the oscillo-





Record	Fault	Location	Oscillograph
1	None		1
2	None		N
3	None		3
4	One turn short circuit	4	3
5	One turn short circuit	6	3
6	One coil short circuit	4	3
7	One coil short circuit	6	3
8	Ground	1	3
9	Ground	5	3
10	Ground	N	3
11	Reversed phase	1 to N	3
12	Reversed coil	N	3

Figure 5. Winding-insulation tester records, double winding

graph deflection is connected to terminal 3, which is normal for production-line testing of windings.

To illustrate the detection of winding faults, turn and coil short circuits and grounds were made at several points in leg 1 and oscillograms taken of the standing waves on the oscillograph screen. Oscillograms 4, 5 and 6 show the two wave traces produced by one-turn short circuits at different points in leg 1, as indicated on the diagram at 4, 5, and 6.

The two waves in each case are offset from each other sufficiently to constitute an unmistakable indication of the winding faults applied. In the same manner oscillograms 7, 8, and 9 show the offset waves obtained with a single-coil short circuit the differences in waves in each case being greater than for the single-turn short circuit. By stopping the synchronous motor and sending all impulses into terminal 1, and viewing the wave, and then into terminal 2 and viewing the wave, it has been determined experimentally that these waves are above and below the no-fault wave of oscillogram 3.

Oscillograms 10, 11, and 12 of Figure 4 show wave shapes corresponding to applied line-to-ground insulation faults at points 1, 5, and *N* of the motor winding. Oscillogram 10 taken with the ground on terminal 1, of course, shows a zero deflection line for the wave applied to that terminal. The single wave of 10 produced by the surge entering terminal 2, corresponds to the double wave of oscillogram 3.

Oscillogram 11 also shows one low-amplitude wave corresponding to the impulse applied at 1 with point 5 grounded and a high-amplitude wave corresponding to the impulse applied at terminal 2. For oscillogram 12 the neutral was grounded, and the waves are superimposed because of the symmetry of this connection arrangement.

These oscillograms and those of Figure 5 which show wave shapes for a double-circuit wye connection illustrate the wide range of surge-voltage variations corresponding to possible insulation faults and connections. A detailed treatment of these is not possible within the scope of this paper. However, stated generally, these wave shapes are determined by the propagation characteristics of the impulse and the magnitudes and directions of induced voltages in the leg connected to the oscillograph. The significance of all this in insulation testing of windings is to be found in the clear-cut manner in which insulation and connection faults are disclosed by the two-way method of surge application and the standing waves on the cathode-ray oscillograph screen.

V. Conclusions

1. A new winding-insulation testing method for completed machine windings has been described.

2. The new method applies suitably controlled voltage wave shapes to give the required turn and conductor insulation stresses for adequate testing practice.

3. The new method provides for immediate detection of insulation faults and winding dissymmetries.

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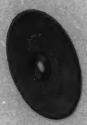

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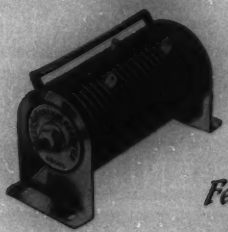

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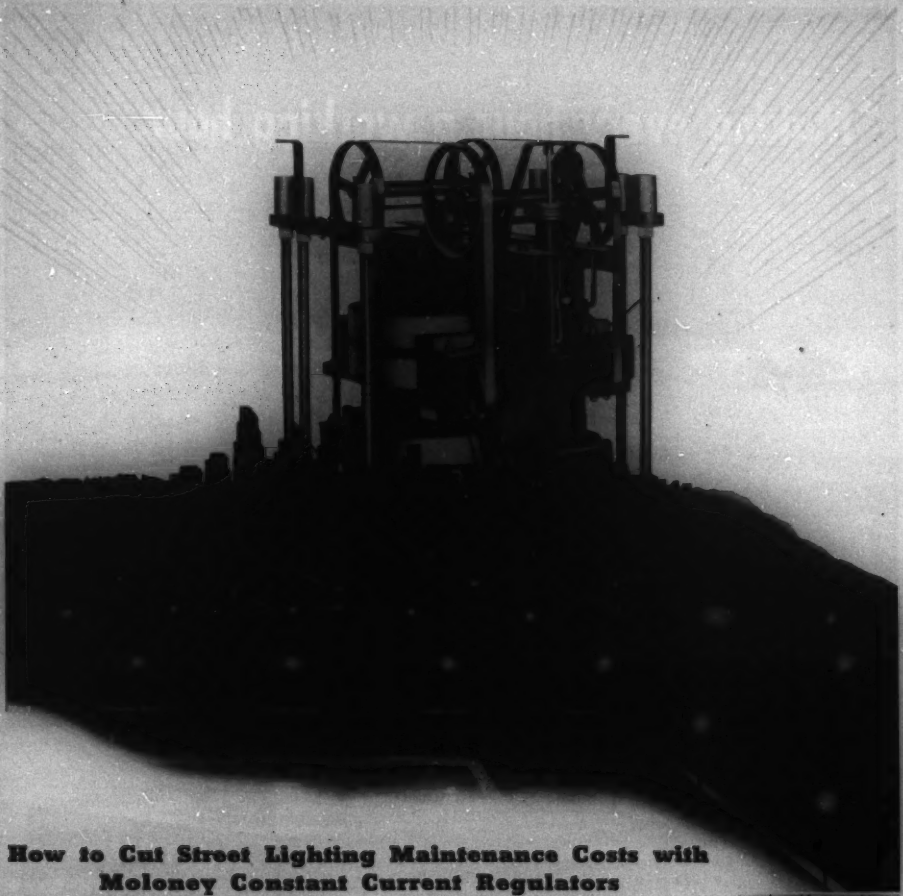

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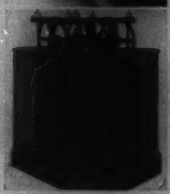

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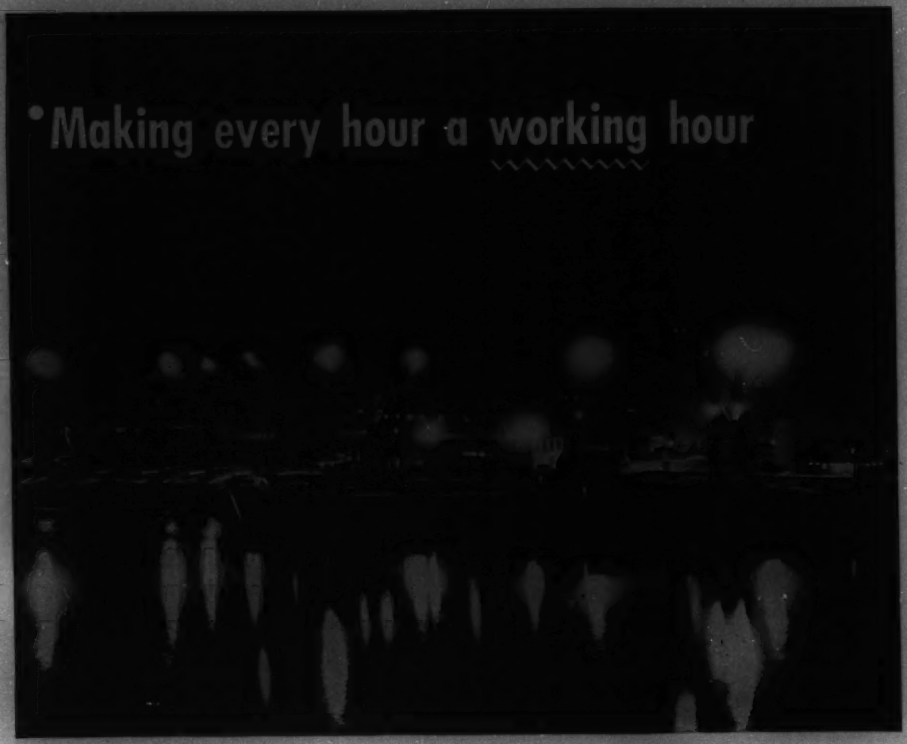

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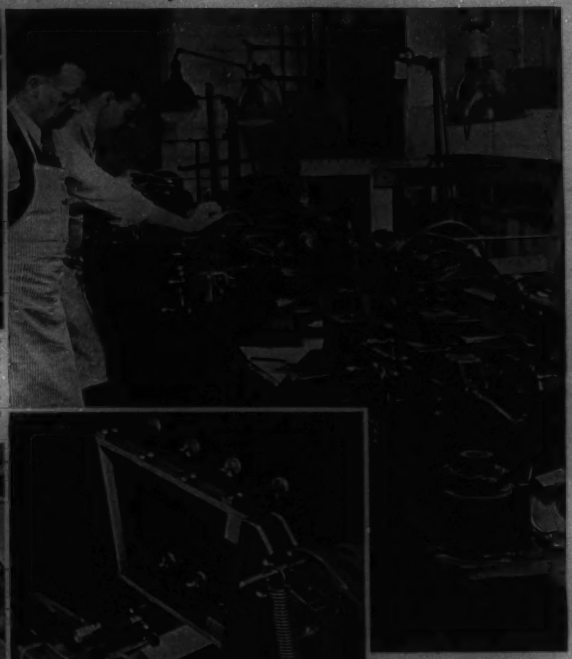

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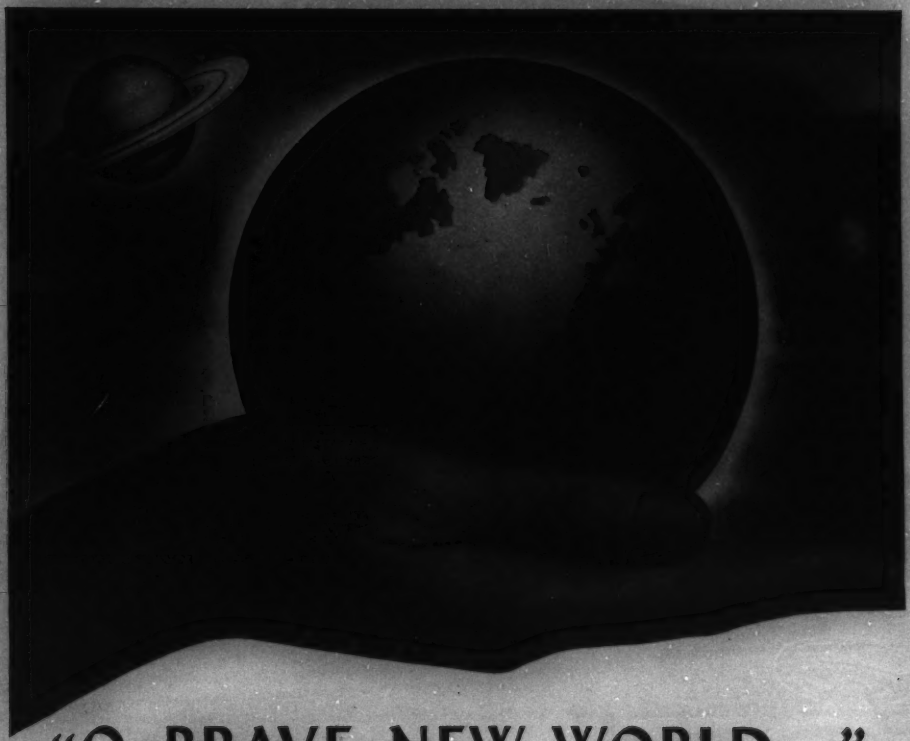

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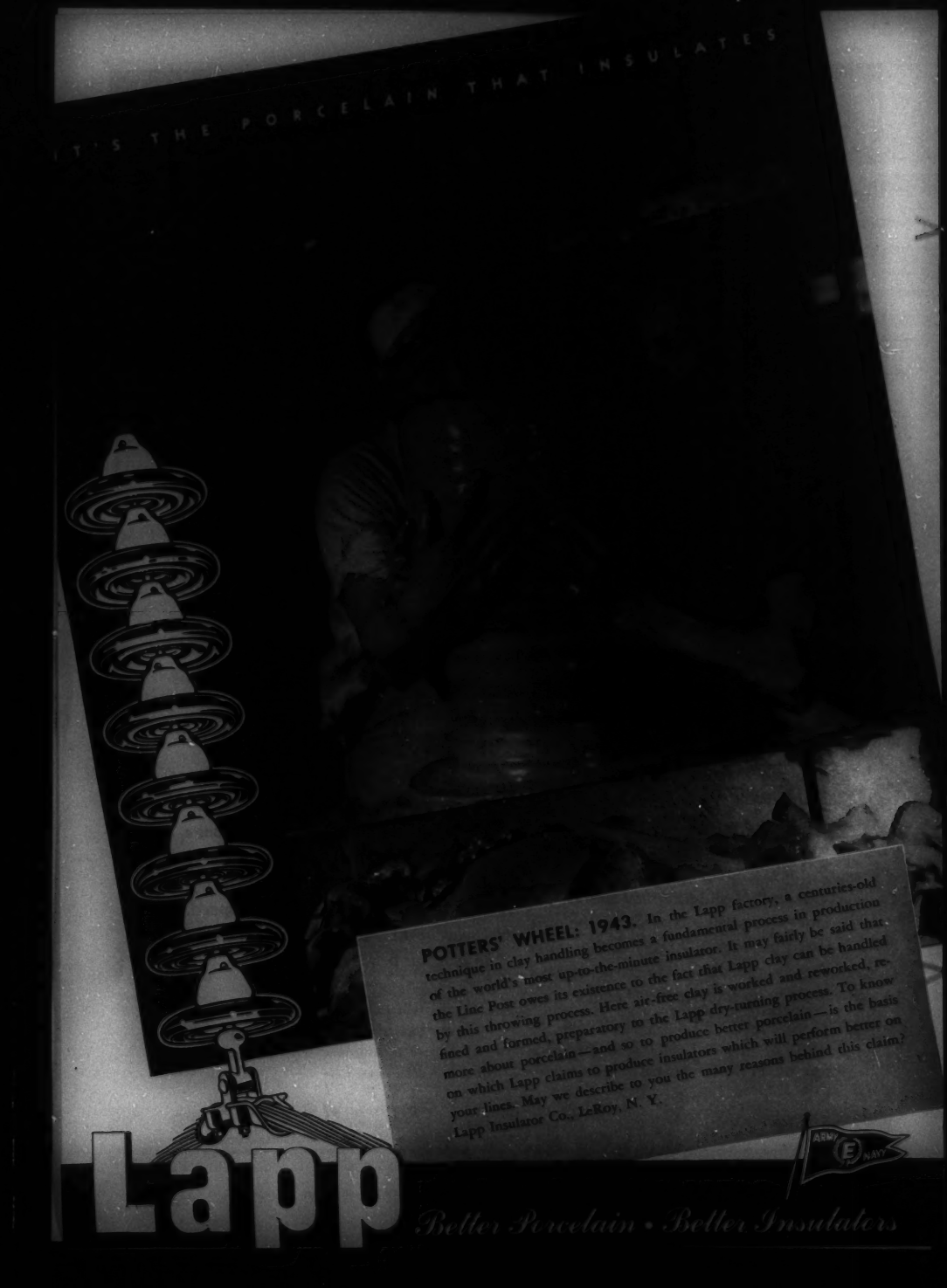
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L&N Type P Combustion control installed on three 150 hp horizontal marine type stoker fired boilers. Panel is at right; note its compact arrangement, with the single Master Controller, three Furnace Pressure Controllers, and all Control Stations mounted on panel front. A typical easy-to-install Drive Unit, for uptake damper, is partially shown at left.

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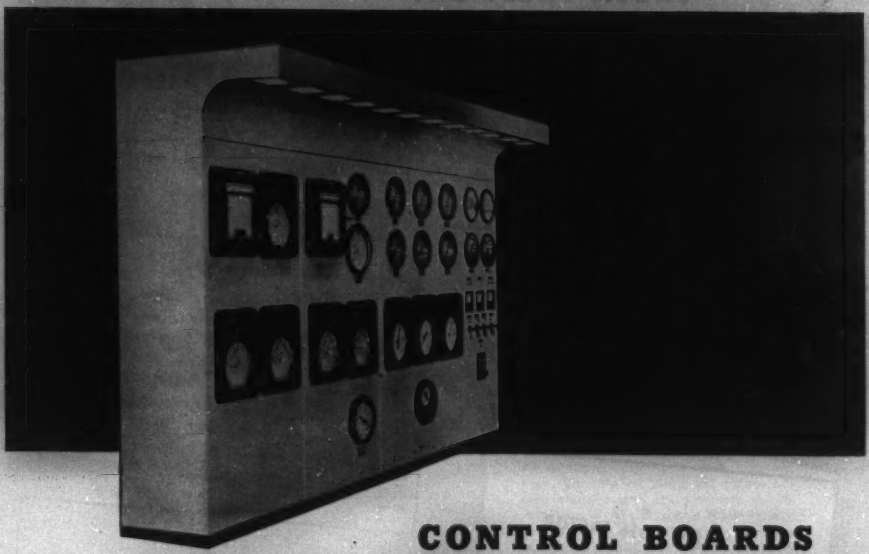

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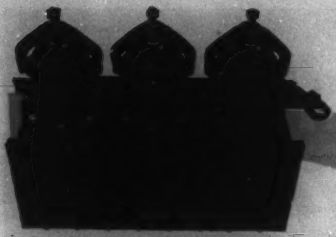
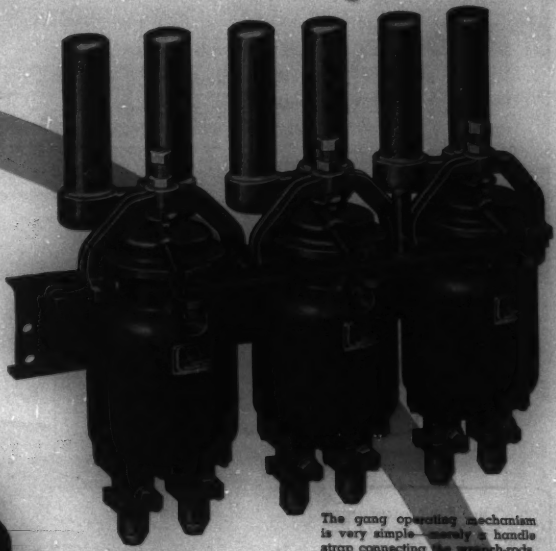


Type "FCBX" fuse-switch boxes provide full metal enclosure of connections. Necessary cable and conduit fittings are attached to the welded steel box.



The gang operating mechanism is very simple—merely a handle strap connecting the wrench-rods.

Beryllium copper springs make ideal switching contacts because they are not subject to fatigue.

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Gang-Operated

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FOR FUSING OR SWITCHING PRIMARY CIRCUITS IN SUBWAY, VAULT AND OVERHEAD INSTALLATIONS

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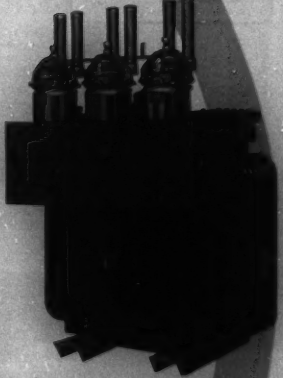

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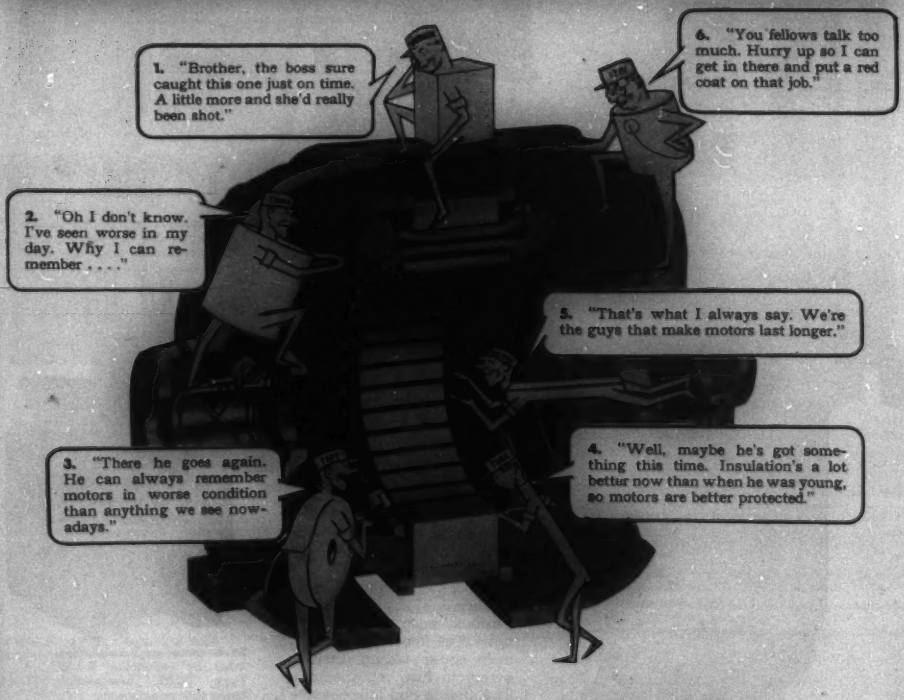
1. "Brother, the boss sure caught this one just on time. A little more and she'd really been shot."
2. "Oh I don't know. I've seen worse in my day. Why I can remember . . . ."
3. "There he goes again. He can always remember motors in worse condition than anything we see nowadays."
4. "Well, maybe he's got something this time. Insulation's a lot better now than when he was young, so motors are better protected."
5. "That's what I always say. We're the guys that make motors last longer."
6. "You fellows talk too much. Hurry up so I can get in there and put a red coat on that job."

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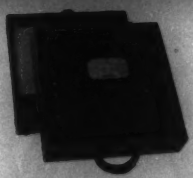
FOR ELECTRONICS MEASUREMENTS, TOO,

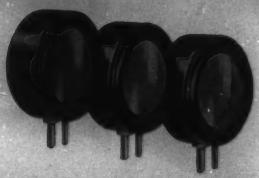
the Standards are Weston

Panel Meters for Electronic applications



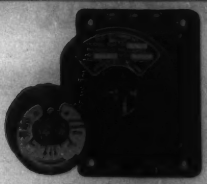
Electronic Circuit Testers

Ultra-Sensitive Laboratory Portables



*Photronic (photo-electric) Cells

Electronic Tube Checkers



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In the field of electronics, too, the measurement tools bear the name most familiar to you. For just as WESTON pioneered fundamental electrical measurement, as well as the special measurement needs of radio, so WESTON has provided simple, precise instruments and devices for the problems encountered in electronics research, production and control. Weston Electrical Instrument Corporation, 597 Frelinghuysen Avenue, Newark, New Jersey.

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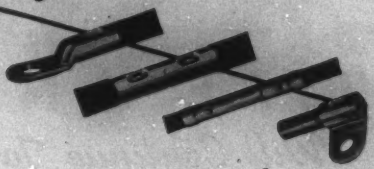

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For example, one VINYLITE Resin Compound can be *extruded* into flexible, non-oxidizing, abrasion- and flame-resistant insulation for electrical wire and cable. Another VINYLITE Elastic Plastic can be *injection molded* into flexible, rubber-like shapes and forms, such as grommets and terminal insulators. Other types can be applied to cloth by *knife-* or *calender-coating* to provide waterproof clothing and paulins that will remain flexible even at −50 deg. F. Rigid VINYLITE Plastic Sheets can be *punched* and *printed* to form accurate *calculating* instruments that are noted for their exceptional dimensional stability. VINYLITE Resins, in solution, can be *sprayed* into cans, containers, drums, and tanks to provide non-toxic, chemical-resistant linings.

The opposite page presents information on the properties, forms, fabricating methods, and applications of VINYLITE Plastics and Resins. For more detailed information, write for technical literature, or call upon our Engineering Staff and Development Laboratories for assistance in solving your essential production problems.

Plastics Division

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"VINYLITE" ELASTIC PLASTICS

These are a relatively new group of VINYLITE Plastics with rubber-like or elastomeric properties. They are produced in a variety of forms, ranging from soft to semirigid. They possess great toughness, and good resistance to continued flexing, and to severe wear and abrasion. Tensile strength is higher than that of most rubber compounds. Their electrical insulating properties are excellent. They are not subject to oxidation. By correct choice of plasticizer, they can be made non-flammable and highly resistant to water, oils, and corrosive chemicals. They are available in a wide range of colors, either translucent or opaque, or can be supplied in their natural, colorless, transparent state. Since all of the VINYLITE Elastic Plastics are thermoplastic, no curing or vulcanizing is required. They are more affected by temperature changes than is rubber, but their operating range is wide, some types remaining flexible at –50 deg. F., yet tack-free at 200 deg. F.

VINYLITE Elastic Plastics are supplied as sheeting and as compounds for calendering onto cloth, as molding and extrusion compounds, or as powdered resins for those industries that, like the rubber industry, possess adequate compounding equipment.

Applications of VINYLITE Elastic Plastics include many products formerly made of rubber, as well as many others that take advantage of their unique properties. Some of these are: non-flammable insulation extruded around wires and cables; flexible, waterproof cloth coatings for rainwear, upholstery, inflatable equipment, and paulins; extruded, transparent or opaque, chemical-resistant tubing; molded grommets, and wire terminal insulators.

"VINYLITE" RIGID PLASTICS

Produced from unplasticized vinyl resins, VINYLITE Rigid Plastics possess a combination of properties found in no other thermoplastic material. Because of their extremely low water absorption, these plastics remain dimensionally stable under widely varying atmospheric conditions. They are outstanding in their resistance to alcohols, oils, and corrosive chemicals. They have high impact strength and tensile strength. They are odorless, tasteless, and non-toxic. They do not support combustion. They are available in a wide range of colors, translucent or opaque, and also in colorless, transparent forms. They are supplied as rigid sheets or as molding and extrusion compounds. Rigid sheets can be fabricated by forming, drawing, blowing, spinning or swaging, and can be punched, sheared, sawed, and machined on standard metalworking tools. Molding compounds are suitable for both compression and injection molding. Extrusion compounds give highly finished continuous rigid rods, tubes, and shapes directly from the die.

Applications of VINYLITE Rigid Sheets include precise calculating and navigating instruments of high dimensional stability; shatterproof gauge glasses and dials for radios, clocks, and instruments; name plates, transparent aircraft enclosures; storage battery separators. Compression-molded applications include transcription records and printing plates; injection-molded uses include safety-goggle frames, combs, pen and pencil barrels. Rigid extrusion compounds are produced as continuous rods, tubes, and shapes by screw extrusion. They are readily fabricated with standard woodworking or metalworking equipment.

"VINYLITE" RESINS FOR SURFACE COATINGS

Correctly formulated and applied, VINYLITE Resins yield finishes of unusual toughness, gloss, adhesion, and chemical resistance. They can be applied by spraying, knife-coating or dipping to a wide variety of surfaces, such as metal, cloth, paper, and concrete. Prepared by dissolving resins in organic solvents, these finishes can be modified with a wide variety of pigments, dyes, and plasticizers. These resins are generally not employed with other film-forming bases, therefore, coatings formulated from them exhibit the desirable features of VINYLITE Resins alone. Drying is solely by evaporation of solvent, and finishes can be either air-drying or baking types.

Applications of vinyl chloride-acetate resins for coatings include container linings, stop-off lacquers for electroplating, corrosion-resistant linings for processing equipment, wall-tile finishes, heat-sealing paper coatings, cement finishes, and waterproof cloth coatings. Coatings based on vinyl butyral resins are also used for waterproof cloth coatings, as on rainwear, hospital sheeting, paulins, and inflatable equipment. Coatings based on these latter resins can be made heat-curing through proper modification.

"VINYLITE" RESINS FOR ADHESIVES

Unusual toughness, resiliency, and impact resistance are characteristic of adhesives made of VINYLITE Resins. These resin adhesives are widely used as bonding agents for such materials as cellophane, cloth, paper, cardboard, porcelain, metal, mica, stone, leather, wood, and plastic sheets and film. They are available as powders for the compounding of adhesives, or as solutions sold under the trade-mark "VINYLSEAL." The latter are especially recommended for bonding impervious materials, such as metals, and the urea and phenolic plastics. Their bonding strength is comparable to that obtained with soft solder. An outstanding example of their use is the lamination of cores of small electric motors. By the addition of plasticizers, adhesives based on VINYLITE Resins can give almost any degree of flexibility desired.

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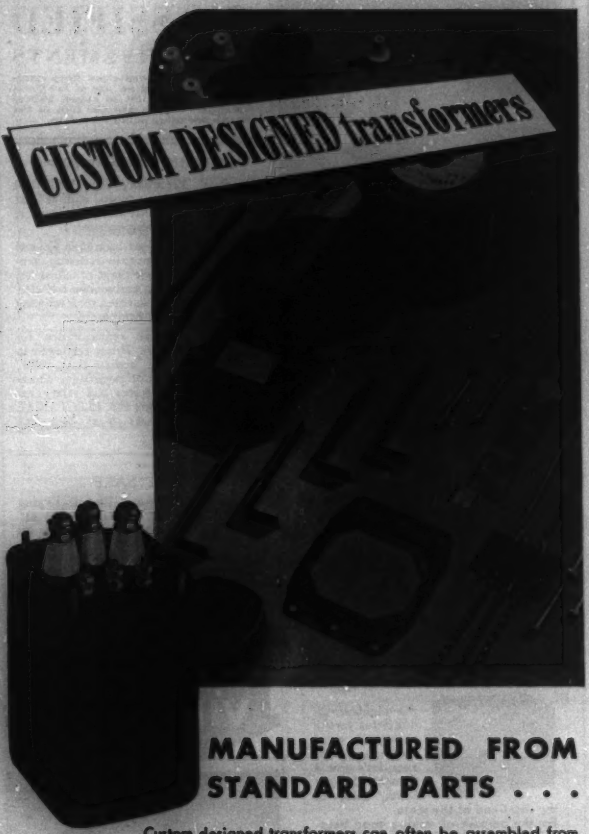

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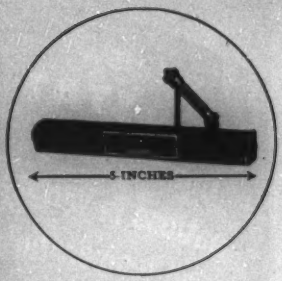

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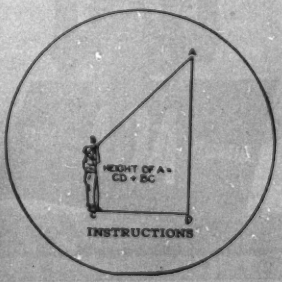

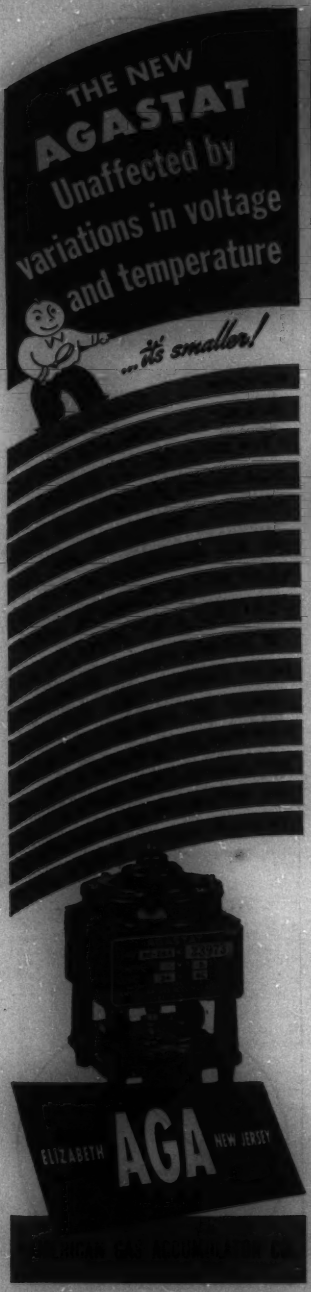

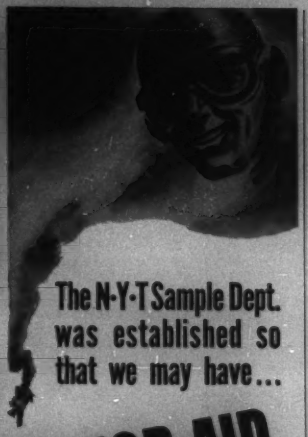

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PRODUCTS CORPORATION
800 Sixth Street, Pittsburgh, Pa.

HERE'S A WARTIME INVESTMENT NEW ELECTRO-COOLER THAT JUMPS POWER TRANSFORMERS 20-60%..AND

QUICK FACTS

EASILY INSTALLED or removed — *without* shifting the transformer. If the transformer has standard radiator valves, there is no need even to drain oil on installation!

FACTORY SEALED! No pipe connections or joints to be made in the field. ELECTRO-COOLER is factory-assembled as a unit.

NO GLANDS or stuffing boxes! Oil drips and air bubbles are eliminated. Never any need to fix packing.

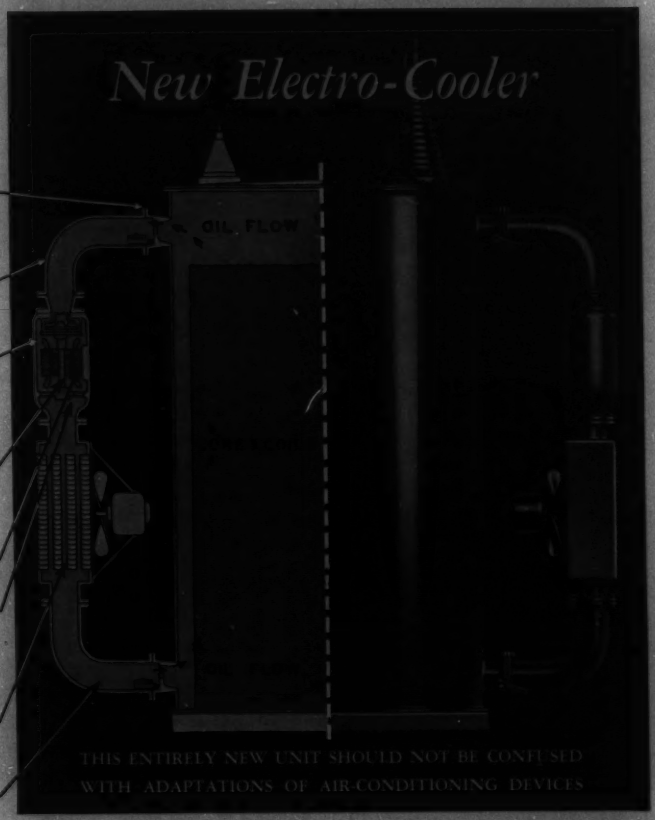
ONLY ONE SHAFT! Motor and pump are designed as a complete unit — on one shaft and in one frame. Result: greater mechanical strength, fewer parts, fewer mechanical fits.

SIMPLICITY! The three-phase squirrel cage motor has no starting brushes, no commutator, nor other such wearing parts to cause trouble.

SELF-LUBRICATED motor and pump are totally enclosed, immersed in oil

HIGH-PRESSURE TESTED! Possibility of oil leaks or seepage is minimized by testing the ELECTRO-COOLER at 50 pounds pressure. Maximum working pressure is only a few pounds.

SELF-CONTAINED and self supporting! The new ELECTRO-COOLER requires no foundations.


New Electro-Cooler
OIL FLOW
THIS ENTIRELY NEW UNIT SHOULD NOT BE CONFUSED WITH ADAPTATIONS OF AIR-CONDITIONING DEVICES

ALLIS-CHALMERS

WITH A GREAT PEACETIME FUTURE: CAPACITY OF MOST ALLIS-CHALMERS SAVES TIME, TROUBLE, SPACE, COST!

★ New ELECTRO-COOLERS can step up capacity of most transformers now in service by 20 to 60%. Installation is simple!

★ Allis-Chalmers' new ELECTRO-COOLER is self-contained and self-supporting... employs no stuffing boxes. Here's the coming thing in forced-oil cooling...a sound long-term investment!

★ New Transformers built with Allis-Chalmers ELECTRO-COOLERS use 25% less copper and steel...cost less!

IF YOUR power transformers are cooled by slow thermo-syphon flow of insulating liquid through their radiators—and most of them are—chances are that new ELECTRO-COOLERS can sharply increase their capacity!

By accelerating liquid flow with pump action — and by forcing cooling air over radiator surfaces — new ELECTRO-COOLERS step up the capacity of most transformers now in service by 20 to 60%!

Installation of new ELECTRO-COOLERS is simple because the units are self-contained and self-supporting. There's no need to shift transformers.

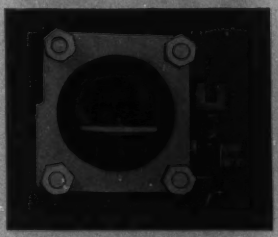
And because the ELECTRO-COOLER is factory-assembled as a unit, there are no pipe connections or joints to be made in the field!

Note that there are no stuffing boxes to require packing — that motor and pump are built on one shaft and in one frame for greater strength and simplicity. Maintenance is *minimum*.

Buying new ELECTRO-COOLERS is smart buying in wartime — and smart buying for the peace years, too. To learn what new ELECTRO-COOLERS can do for *your* system, call the district office near you. ALLIS-CHALMERS MFG. CO., MILWAUKEE, WIS.

A 1377

FINAL TESTING of 20,000 kva transformer equipped with new ELECTRO-COOLERS.



NO NEED to drain oil if transformer has this standard radiator valve!

TRANSFORMERS

WE WORK FOR VICTORY — WE PLAN FOR PEACE

. . . the Highest Standard in Magnetic Measurements

To maintain a high degree of uniform magnetic quality and precision, Arnold engineers use The *High H Permeameter* (illustrated) . . . *a duplicate of the Permeameter in use at the National Bureau of Standards* . . . just one example of the close magnetic control under which the Arnold magnets are manufactured.

All ALNICO types of Permanent Magnets . . . including ALNICO V . . . are completely fabricated in the Arnold plant under exacting metallurgical, mechanical and magnetic control.

Arnold engineers are available to solve your magnetic design problems . . . all inquiries will receive prompt attention.

★ FOR VICTORY . . . invest at least 10% in War Bonds. ★

THE ARNOLD ENGINEERING COMPANY

147 EAST ONTARIO STREET • CHICAGO, ILLINOIS

PRODUCERS OF MAGNETS FOR AIRCRAFT, MARINE, RADIO, ELECTRICAL AND OTHER TYPES OF MEASURING INSTRUMENTS

For Your Laboratory, Product, or Production Line

VARIABLE VOLTAGE

Varitran

★ Output voltage 0 to 130 volts. ★ Continuously variable. ★ Input voltage 115 volts (or 230 V.) ★ Efficiency over 95%. ★ Regulation under 4%. ★ No wave form distortion. ★ The ideal variable voltage transformer. ★ Sizes from 230 to 3500 watts.

UNITED TRANSFORMER CO.

Specialists for over a generation in

OIL IMMERSED MOTOR CONTROL

ROWAN CONTROL

THE ROWAN CONTROLLER CO., BALTIMORE, MD.

SHALLCROSS ROTARY TAP SWITCHES USE SOLID SILVER CONTACTS, BECAUSE SOLID SILVER . . .

1. Has the highest conductivity of materials available.
2. Is superior to silver-plating which wears off, resulting in high resistance contacts.
3. Should it corrode the sulphide formed does not appreciably increase the contact resistance.

Let Shallcross answer your switch problems
Address Dept. C 9

WHY "SHORTING" AND "NON-SHORTING" SWITCHES?

This is the shorting type. As the arm is rotated from one position to another the adjacent contact points are "shorted" (bridged).

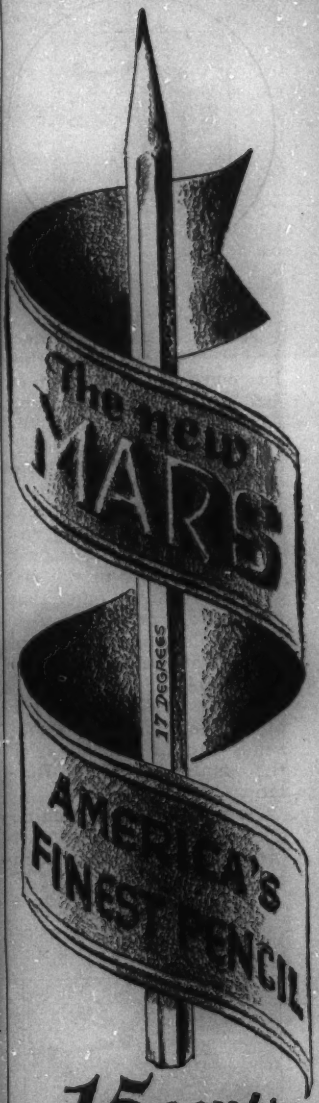
This is the non-shorting type. As the arm is rotated from one position to another, the arm lifts up, and only one contact is touched at a time.

Creators and Makers of

ACCURATE RESISTORS—SWITCHES—SPECIAL EQUIPMENT AND SPECIAL MEASURING APPARATUS FOR PRODUCTION AND ROUTINE TESTING OF ELECTRICAL EQUIPMENT ON MILITARY AIRCRAFT . . . SHIPS . . . VEHICLES . . . ARMAMENT . . . AND WEAPONS

SHALLCROSS MFG. CO.

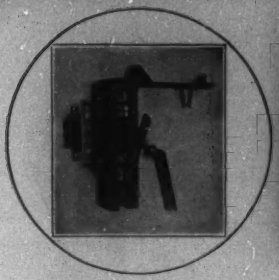
COLLINGDALE, PENNA.



15 cents

"DEMAND THE BEST!"

J. S. STAEDTLER, INC.
53-55 WORTH STREET
NEW YORK, N.Y.



300 Ampere, Catalog 275

Compact

A New Jersey engineer had the fallacious idea that he couldn't get eighteen 400 ampere disconnecting switches in an available space of 21 feet.

Then he learned that Matthews Disconnecting Switches were only 3⅞ inches wide in the 200 and 400 ampere ratings and only 4¾ inches wide in the 600 ampere rating, and that they are all rated 7500 volts. His problem was solved and he had ample space to do a neat job.

This is their 14th year of successful service. Thousands are in use all over the country. Send for Bulletin

Do you want to examine a sample? It will be sent prepaid on request, on loan account.

W. N. MATTHEWS CORPORATION
ST. LOUIS, U. S. A.

600 Ampere, Catalog 675

PERMANENT MAGNETS

New Steels and New Processing Methods are producing

BETTER MAGNETS

WITHIN the past few years, rapid progress has been made in the practical application of permanent magnetism. Much more is known about the subject. Designs of magnets have been improved. Better steels are available. Processing is more precise and under better control.

Those interested in the design of permanent magnets or in the selection of magnet steels should investigate ALNICO and NIPERMAG, two recently perfected steels with exceptionally high energy content.

CINAUDAGRAPH CORPORATION
STAMFORD, CONNECTICUT

TRANSFORMERS THAT FIGHT BATTLES AND BREAK PRODUCTION BOTTLE-NECKS

On the battle fronts of the world Acme Transformers are giving a good account of themselves. If you, too, need transformers that are built to meet emergency performance beyond the requirements of the application, then get in touch with Acme Electric transformer specialists.

Sealed-case transformers for air-borne communication equipment. These transformers successfully withstand climatic and temperature conditions of the steaming tropics or the intense cold of the 40,000 ft. altitude.

High voltage plate supply transformer for transmitter. 33,000 volt, 1.8 ampere secondary, 230 volt, 60 cycle primary.

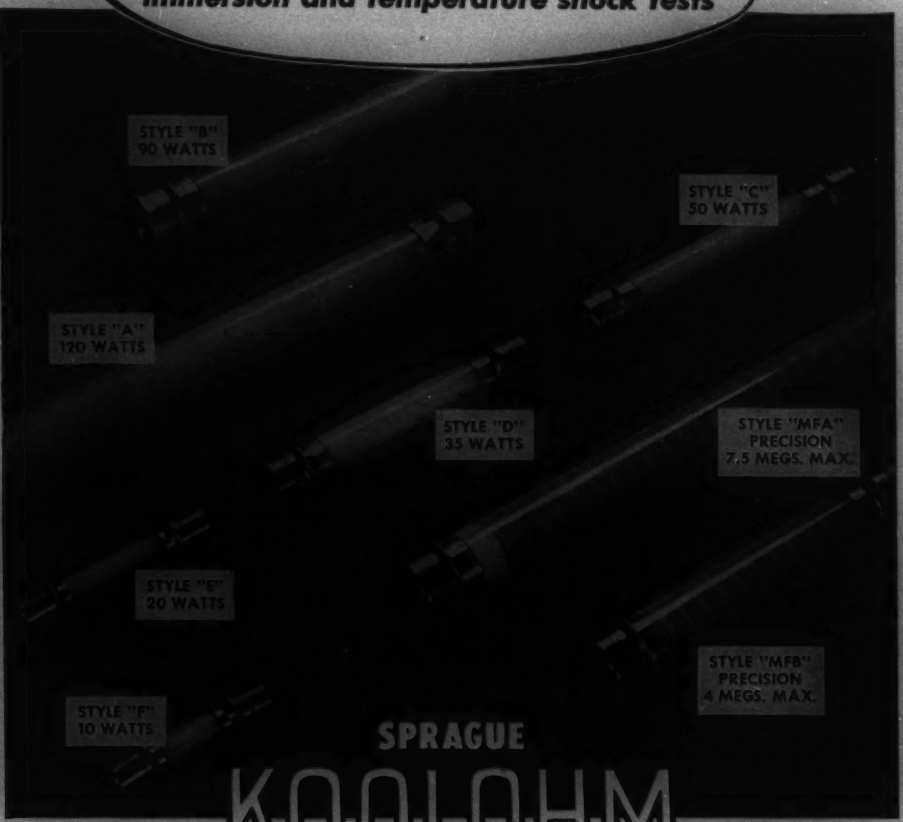
A manually operated full range stepless voltage control unit, from 0 to 135 volts. Regulation accurate to within 4/10 volt adjustment. Not a resistance regulator; output voltage is independent of load. Panel and portable types. Write for Bulletin 150.

THE ACME ELECTRIC & MFG. CO.
22 Water St. Cuba, New York

Acme Electric TRANSFORMERS

THE ONLY REAL HERMETICALLY-SEALED RESISTORS

...that will stand the most severe salt water immersion and temperature shock tests


STYLE "B" 90 WATTS
STYLE "C" 50 WATTS
STYLE "A" 120 WATTS
STYLE "D" 35 WATTS
STYLE "MFA" PRECISION 7.5 MEGS. MAX.
STYLE "E" 20 WATTS
STYLE "MFB" PRECISION 4 MEGS. MAX.
STYLE "F" 10 WATTS

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KOOLOHM

POWER WIRE WOUND RESISTORS AND METER MULTIPLIERS

These Koolohms, designed for the toughest resistor applications facing the industry today, again emphasize the importance of exclusive Koolohm construction features combined with Koolohm engineering ingenuity in solving almost any wire wound resistor problem.

For Koolohms are entirely different from conventional wire wounds. There are no other resistors like them. No other type of resistor can match their performance on exacting jobs. AVAILABLE WITH NON-INDUCTIVE WINDINGS. Get the facts! Write for catalog and sample Koolohms. SPRAGUE SPECIALTIES COMPANY (Resistor Division), North Adams, Mass.

FREEZE 'EM OR FRY 'EM

• Global war means airplanes in the Arctic. It means tanks in the tropics. For fighting machines of all kinds, combat conditions call for freezing or frying — and sometimes both!

Solar is building capacitors which meet these extreme conditions. If "freezing or frying" is part of your capacitor problems — call on Solar's "temperature-engineering" services.

Facts and more facts. Complete capacitor data describing and illustrating the entire Solar line is now available to design engineers on request.

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SOLAR

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ARMY E NAVY

CAPACITORS

MAKERS OF CAPACITORS: ELECTROLYTIC • MICA • PAPER • TRIMMER • TRANSMITTING

LAUGH AT "THEM GREMLINS"*

Kuhlman ELECTRIC COMPANY BAY CITY MICHIGAN

CONTROLLING MILLIONS OF VOLTS!

Electron beam tube of atom-smasher.

In the vast new province of Nuclear Physics the atom-smashing "Big Guns"—the Van de Graaff generators, the cyclotrons and betatrons—are carrying on a campaign of *creative* destruction.

Manned by an army of collaborating specialists, this massive and complex artillery has already achieved spectacular results in the medical, chemical and biological fields and in scientific developments which must remain secret for the duration. The "smashing" of atoms has released new energies, created new atoms.

Despite the tremendous force required to produce high-speed electrons, protons and ions, the controls and measuring devices perform with amazing accuracy.

IRC is proud to have contributed to the development of resistor units, both Wire Wound and Metallized—of fixed and variable types—used in the measuring instruments. And IRC engineers have produced special resistors used to stabilize corona and other disturbing phenomena in atom-smashers.

If you are confronted with a problem involving resistance devices, we invite your inquiry. Our engineering staff, specialists in the design of all types of resistors, can be depended upon for impartial counsel.

* PREFERRED FOR PERFORMANCE *
IRC
* FIXED & VARIABLE RESISTORS *

INTERNATIONAL RESISTANCE COMPANY

427 N. BROAD ST., PHILADELPHIA

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